Vol. 34, No. 1 February, 1944

Journal of Experimental Psychology

EDITED BY

SAMUEL W. FERNBERGER, ON LEAVE
FRANCIS W. IRWIN, ACTING EDITOR
UNIVERSITY OF PENNSYLVANIA

CONSULTING EDITORS

CHARLES W. BRAY, *Princeton University;* ELMER K. CULLER, *University of Rochester;* CLARENCE H. GRAHAM, *Brown University;* JOY P. GUILFORD, *University of Southern California;* FRANCIS W. IRWIN, *University of Pennsylvania;* DONALD G. MARQUIS, *Yale University;* ARTHUR W. MELTON, *University of Missouri;* CARROLL C. PRATT, *Rutgers University.*

CONTENTS

Distortion in the Perception of Real Movement: H. L. ANSBACHER 1

Spectral Saturation and Its Relation to Color-Vision Defects: A. CHAPANIS .. 24

Some Effects of Mental Set and Active Participation in the Conditioning of the Autokinetic Phenomenon: E. A. HAGGARD AND G. J. ROSE 45

Visual Subliminal Perception Where a Figure is Obscured by the Illumination of the Ground: H. E. KING, C. LANDIS AND J. ZUBIN 60

The Effect of Controlled Temperature Changes on the Behavior of the White Rat: K. MOORE 70

Eye Movements in Reading Optimal and Non-Optimal Typography: D. G. PATERSON AND M. A. TINKER 80

Consistent Conditioned Hand-Withdrawal in the Elementary Laboratory: H. SCHLOSBERG 84

PUBLISHED BI-MONTHLY,
BY THE AMERICAN PSYCHOLOGICAL ASSOCIATION, INC.
PRINCE AND LEMON STS., LANCASTER, PA.
AND NORTHWESTERN UNIVERSITY, EVANSTON, ILLINOIS

Entered as second-class matter, February 6, 1937, at the post office at Lancaster, Pa., under the Act of March 3, 1879

PUBLICATIONS OF

THE AMERICAN PSYCHOLOGICAL ASSOCIATION

WILLARD L. VALENTINE, *Business Manager*

PSYCHOLOGICAL REVIEW

HERBERT S. LANGFELD, *Editor*
Princeton University

Contains original contributions only, appears bi-monthly, January, March, May, July, September, and November, the six numbers comprising a volume of about 540 pages.
Subscription: $5.50 (Foreign, $5.75). Single copies, $1.00.

PSYCHOLOGICAL BULLETIN

JOHN E. ANDERSON, *Editor*
University of Minnesota

Contains critical reviews of books and articles, psychological news and notes, university notices, and announcements. Appears monthly (10 issues), the annual volume comprising about 665 pages. Special issues of the BULLETIN consist of general reviews of recent work in some department of psychology.
Subscription: $7.00 (Foreign, $7.25). Single copies, 75c.

JOURNAL OF EXPERIMENTAL PSYCHOLOGY

S. W. FERNBERGER, *Editor, on Leave,* FRANCIS W. IRWIN, *Acting Editor*
University of Pennsylvania

Contains original contributions of an experimental character. Appears bi-monthly (beginning 1944), one volume per year, each volume of six numbers containing about 520 pages.
Subscription: $7.00 (Foreign, $7.25). Single copies, $1.25.

PSYCHOLOGICAL ABSTRACTS

WALTER S. HUNTER, *Editor*
Brown University

Appears monthly, the twelve numbers and an index supplement making a volume of about 700 pages. The journal is devoted to the publication of non-critical abstracts of the world's literature in psychology and closely related subjects.
Subscription: $7.00 (Foreign, $7.25). Single copies, 75c.

PSYCHOLOGICAL MONOGRAPHS

JOHN F. DASHIELL, *Editor*
University of North Carolina

Consist of longer researches or treatises or collections of laboratory studies which it is important to publish promptly and as units. The price of single numbers varies according to their size. The MONOGRAPHS appear at irregular intervals and are gathered into volumes of about 500 pages.
Subscription: $6.00 per volume (Foreign, $6.30).

JOURNAL OF ABNORMAL AND SOCIAL PSYCHOLOGY

GORDON W. ALLPORT, *Editor*
Harvard University

Appears quarterly, January, April, July, October, the four numbers comprising a volume of 560 pages. The journal contains original contributions in the field of abnormal and social psychology, reviews, notes and news.
Subscription: $5.00 (Foreign, $5.25). Single copies, $1.50.

JOURNAL OF APPLIED PSYCHOLOGY

DONALD G. PATERSON, *Editor*
University of Minnesota

Covers the applications of psychology in business, industry, education, etc. Appears bi-monthly, February, April, June, August, October, and December.
Subscription: $6.00. Single copies, $1.25.

Subscriptions, orders, and business communications should be sent to

THE AMERICAN PSYCHOLOGICAL ASSOCIATION, INC.

NORTHWESTERN UNIVERSITY, EVANSTON, ILLINOIS

Journal of
Experimental Psychology

VOL. 34, NO. 1 FEBRUARY, 1944

DISTORTION IN THE PERCEPTION OF REAL MOVEMENT

BY H. L. ANSBACHER

Brown University

I. INTRODUCTION

(1) *Description of the phenomenon.*

(*a*) *Historical considerations.*—In the course of his experimenting with recurrent vision on the modified McDougall wheel of Kellogg (**19**) at Columbia University, 1937, Harold C. Brown changed the radial rotating light stimulus into a rotating arc of approximately 36° and discovered the following phenomenon:

If one rotates such an arc at one revolution per second, it is seen as a mere point, provided one does not follow it with the eyes. Eye fixation can be accomplished easily by looking at any convenient point in the set-up, e.g., the axis of the rotating disk. At fast rotation rates, of course, fusion results, and the arc is seen as a complete circle.

Up to the limits of eight feet (the maximum he was able to use), variations in distance did not affect the phenomenon. Likewise variations in room illumination were not critical.

Brown has never published his observation. Its first published account is in an abstract of a paper read by the present writer (**2**).

(*b*) *Systematic considerations.*—The phenomenon represents an aspect of the visual perception of real movement. Such perception may occur in two ways:

(1) A moving object may be perceived as moving, by pursuing it with one's eyes. In this way the picture of the object remains stationary in reference to a specific portion of the retina, while the background shifts.

(2) A moving object may be perceived as moving while the eyes remain fixed on some stationary point in the visual field. In this way, it is the picture of the object which shifts in reference to the retina,

while the picture of the background remains stationary. Hereinafter, we shall refer to this kind of perception as FMP, for Fixation Movement-Perception.

The phenomenon on which this paper is based is concerned with one incidental aspect of FMP, namely, the distortion of the real stimulus.

(2) *Literature.*

Three lines of research have been concerned with distortions incidental to FMP.

(*a*) *The anorthoscopic approach.*—Zöllner (**30**) described the phenomenon of the so-called anorthoscopic distorted figures as follows: Certain simple figures are moved behind a narrow slit of approximately two mm. width and eight cm. height. (1) When moving at relatively high speed, they appear narrower than they actually are. (The figures are perceived simultaneously.) This is the aspect of our present concern. (2) When moving at relatively low speed, they appear wider than they actually are. This situation is, according to H. Hecht (**17**), quite certain to have little relationship to the first. (Here the figures are perceived successively.) (3) In both situations (1 and 2), the figures appear considerably wider than the slit behind which they move, the outstanding characteristic of the anorthoscopic approach. For Helmholtz (**18**, p. 749) the explanation of the distortions lay in involuntary pursuit eye movements: movements slower than the actual speed in situation 1 and faster than the actual speed in situation 2. Zöllner disputed this explanation, and Rothschild (**23**) dismissed it definitely.

Various other aspects of the anorthoscopic phenomenon were studied by Vierordt (**26**), Gertz (**16**), and more recently by several students of F. Schumann: Rothschild and Hecht, to whom we have just referred, Wenzel (**28**), and Volk (**27**). The Schumann group established that the perceived figure is essentially influenced by various attributes of the slit, and other Gestalt factors. For the distortion as such, "a psychophysical mechanism must be assumed which transforms a temporal phenomenon into a spatial one" (Hecht, **17**). The principal characteristic of the Zöllner set-up, however, that the seen figure is at all events wider than the slit, remained without a satisfactory theory (Koffka, **20**, p. 1199).

Zöllner's set-up was a simplification of the early stroboscope in which FMP distortion had been observed. Descriptions of the stroboscope and its many variations may be found in Boring (**7**, pp. 588 ff.).

Summary: FMP distortion was first observed with the anorthoscopic set-up, which, however, included too many inseparable variables to have invited further research.

(*b*) *Ehrenstein's approach.*—Ehrenstein (**9**) studied FMP distortion in a set-up without a slit, where single figures were made to pass in front of the observer's eye on an endless band. Here, of course, eye fixation became a real problem. Therefore, Ehrenstein later (**11**) shielded part of the path of the band, leaving an opening of 10 to 30 cm., wide enough to preclude the occurrence of the principal anorthoscopic characteristic.

Ehrenstein found that at optimal FMP speeds figures appear narrowed in the direction of their movement. Among other Gestalt factors, he (**11**) also found that (1) the more impressive parts of a whole Gestalt (*Komplex*) advance more slowly than the other parts, and (2) that change in configuration of moving figures may be due to intrafigural apparent movement and to the resulting simultaneous contrast of movement. Earlier Ehrenstein (**10**) had found that figures adapt themselves to the contour of the slit, confirming results of the Schumann group. His ultimate principle of explanation, that FMP distortions are "complex qualities, jointly produced by the sense of space and the sense of movement," is almost identical with that offered by Hecht.

This explanation could be expressed in constancy terminology. Brunswik (Ansbacher, **1**) would call FMP distortion a compromise object between the intended pole of width and the unintended pole of time spent by the stimulus on its path. The work of Brown (**8**) on the visual perception of velocity should be mentioned here, in which he used two movement fields which differed only with respect to their size and obtained different apparent velocities.

Summary: Ehrenstein studied FMP distortion in a set-up which was free from the Zöllner anorthoscopic encumbrances, and offered Gestalt explanations.

(*c*) *Fröhlich's approach.*—When in FMP a vertical line is observed moving behind an opening, it does not appear at the entrance edge but at a distance away, while it disappears at the exit edge. This phenomenon was studied extnesively by Fröhlich (**13**, **14**, **15**, and others), who thought that the time difference between the actual and the seen appearance of the moving line afforded a measurement of 'sensation time.' While the observation remained uncontested, Fröhlich's implications became the objects of a wide controversy.

Summary: Fröhlich's studies and others in this connection show that the entrance and conditions of entrance of a stimulus into the visual field constitute phenomena in their own right.

(3) *Comparison of the present method with the previous ones.*

As against the various approaches discussed, the present one affords the study of FMP distortion free from all further concomitants. Specificically:

(1) The anorthoscopic phenomenon is eliminated by not using a narrow slit.

(2) The influence of a wide slit on the seen figure is eliminated by not using any shield.

(3) Eye fixation offers no difficulty.

(4) The fact that the rotating stimulus remains continually within the visual field (*a*) eliminates the psychological factors of the beginning and end of an activity, (*b*) permits the observer to make his judgment leisurely at his convenience rather than in the tense set of having to catch a fleeting impression, and (*c*) permits quantification.

II. Problem and Method

The problem of this study was to investigate (1) how the phenomenon described at the outset would vary with speed, (2) whether the observed shrinkage is a dropping out of parts of the stimulus or a psychological telescoping, and (3) how the shrinkage is affected by the shape of the stimulus.

(1) *Apparatus.*

A modified McDougall wheel at Columbia University was used as constructed and described by Kellogg (19). Its diameter was two feet. It permitted the insertion of various stencils into a section and was illuminated from behind a milk glass by four 25-watt bulbs, so that the stencil patterns were seen as light figures on black ground.

In front of the center of the wheel a flat black box (presenting the variable) was mounted, illuminated separately, from within. On the side of the box facing the observer, a horizontal line was cut in a stencil, covered on the back by white paper. The illuminations of this line and of the stencil pattern of the main apparatus were subjectively equated. The length of the line could be varied through rolling shutters, manipulated by the experimenter. The center of the line was in front of the axis of the wheel and was marked as the fixation point. The box did not obstruct the main pattern on its circular path. The apparatus is shown in Fig. 1.

(2) *Experimental situation.*

The experiments took place in ordinary room illumination. The observers sat two to four feet away from the apparatus. The instructions were: "You will see two illuminated figures: one stationary line here in the center, the length of which can be varied, and some other design rotating around the periphery of the disc in front of you. Look at the mark in the center of the stationary line. The line will at one time be very short at the beginning and expand slowly, the next time it will be long at the beginning and contract slowly. When the stationary line which is slowly being lengthened or shortened seems to you to be equal in length to the line or figure you see moving around it, say 'Now.' Make judgments only when your eyes are fixated on the center point of the line. Make quick judgments; do not deliberate in any way. We are not interested in how correctly you judge the actual length of the figure; we only want to know how long the figure seems to you. Everything will be explained to you at the end of the experiment."

Then the wheel was set to rotate, the lights in both the standard and variable were turned on —which served as cue to get ready—and the variable was slowly lengthened or shortened. When

the observer said 'Now,' the apparatus lights were turned off, and the length of the variable (the judgment) was measured.

The method of limits was used. An average of four judgments was obtained for each situation, except in Experiment I where 10 judgments were used.

(3) *Observers.*

The observers were undergraduate and graduate students and older college graduates, in part unfamiliar with psychological experimentation, 40 in all. Since the problem was explained at the end of the session, no observer was used twice; some sessions consisted of several experiments. There were 8 to 12 observers per experiment.

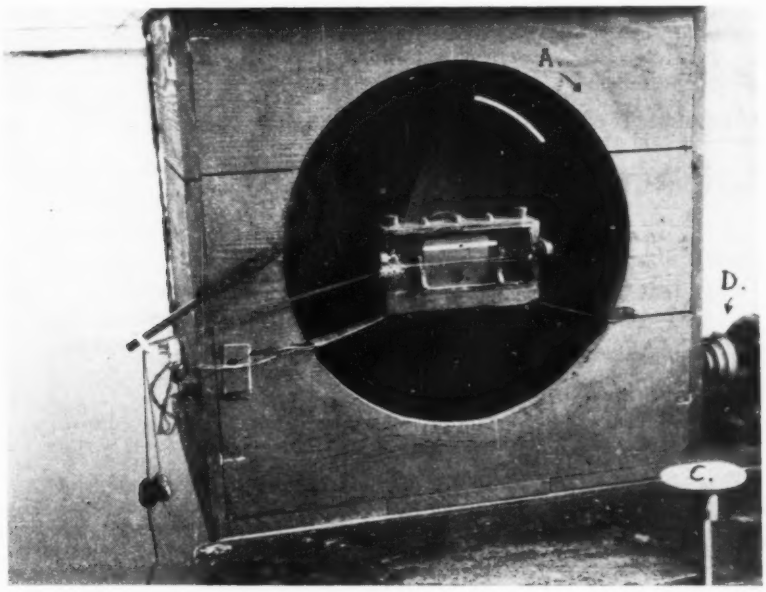

FIG. 1. The apparatus

Diameter of the disk: 50 cm.

A: Moving arc stimulus illuminated from behind, the standard, 13 cm. long. *B*: Adjustable line illuminated from behind, operated by the experimenter, the variable, with the eye fixation point. *C*: Chin rest for the observer, about 3 feet away from *B*, used only in the beginning of the study and abandoned when found unnecessary. *D*: Constant-speed motor with various adjustments.

Actually the entire apparatus was uniformly black. Different shades appear in the photograph due to overexposure.

III. EXPERIMENTS I–IV AND RESULTS

Experiment I: An arc as the moving stimulus (basic experiment).

Purpose: To determine the relationship of the extent of shrinkage of an arc to variation in speed.

Procedure:

The standard was an arc at a radial distance of 20.7 cm. It was 13 cm. long (1/10 of the circumference of its circle) and .4 cm. wide. Speeds of 0, .5, .7, 1, and 1.3 revolutions per sec. were used. Judgments were obtained from 12 observers.

Results: The results are presented in Table I and Fig. 2 and are briefly: The greater the speed, up to the maximum investigated, the shorter the apparent length of the stimulus. No exception from this general trend was found, and there were reversals in only three cases.

TABLE I

SHOWING APPARENT LENGTH IN CM. OF 13 CM. ARC ROTATING AT VARIOUS SPEEDS (EXPERIMENT I)

	Obs. No.	Rotation Speed in Revolutions per Second				
		0	0.5	0.7	1	1.3
Group 1 starting with 0 r.p.s.	1	6.9	5.1	2.7	1.3	0.8
	2	10.6	7.4	13	8.6	4.9
	3	9.9	8.6	9.4	9.6	5.4
	4	11	6.4	4.1	2.9	1.8
	5	11.6	10.2	7.7	4.9	3.7
	6	11.6	10.8	9	8.3	6.7
Average 1–6		10.2	8.1	7.6	5.9	3.9
Group 2 starting with 1.3 r.p.s.	7	10.2	9.2	6.1	0.8	0.6
	8	12.8	12	7.5	1.6	1.5
	9	11.4	11.5	8.8	1.2	1.4
	10	13.8	12.6	11.5	10.4	1.8
	11	12.1	12.2	10.5	7.7	1.5
	12	13.4	13.9	10.4	5.4	2.5
Average 7–12		12.3	11.9	9.1	4.5	1.5
Average for both groups combined.....		11.3 ±1.75	10	8.4	5.2	2.7±1.74

Average 0 r.p.s. vs. average 1.3 r.p.s.: D/Sigma D = 10.25

For observers 1 to 6 the sequence of speeds was ascending, from slow to fast; for observers 7 to 12 it was descending, from fast to slow. For the first group subjective size ranged from 10.2 to 3.9 cm. for lowest to highest speed; for the second group, from 12.3 to 1.5 cm. This difference is to be explained as follows: In group 1 a certain set of resistance to the phenomenon is created. Starting with no movement, the observer receives information, so to speak, as to the real length of the stimulus and subsequently resists seeing it shortened in movement, especially since he frequently expects the opposite. Observers 2 and 3, who showed the reversals, spontaneously stated that they felt they were underestimating the length. The observer with the highest values showed a critical attitude in general. The second

group, starting with the highest speed, could not but yield fully to the phenomenon. The greater apparent length at the subsequent lower speeds can be explained by contrast effect: having seen the stimulus as very small at first, it looks particularly large at the slow speeds. Consequently, later experiments, in which we were interested in measuring the greatest extent of shrinkage, were started with the highest speed, whenever speed was a variable. Incidentally, in both groups the observers were frequently so unknowing that they thought the length of the stimulus had been changed from setting to setting, rather than the speed.

Speed was not increased beyond 1.3 r.p.s. because at this point the maximum possible shrinkage was obtained in most cases. Greater speed at informal trials eventually brought about multiplication of the perceived object, and ultimately fusion, in accordance with a similar observation by Metzger (**22**).

Summary: The greater the speed, the shorter the apparent length of the stimulus.

Experiment II: [1] Sine curve as the moving stimulus.

Purpose: To determine whether the shrinkage observed in Experiment I is due to a dropping out of any part of the stimulus or to a perceptual telescoping.

Procedure:

In preliminary trials it was found that a curve offered greater resistance to shrinkage than the straight arc, which agrees with Rothschild (**23**), according to whom structured figures offer greater resistance to distortion than unstructured stimuli. Furthermore, a sine curve beginning and ending with blunt parts was found to shrink less than one beginning and ending with pointed parts.

In the experiment proper two sine curves were used, one with blunt parts and one with pointed parts forming the beginning and end. (See corresponding diagrams in Fig. 2.) Both curves were 13 cm. long, .4 cm. wide, and had two peaks. The distance of the peaks from the center of the disk was 19.5 cm., the distance of the valleys, 16.2 cm. The amounts of illuminated surfaces were 7.44 sq. cm. and 7.32 sq. cm., respectively.

The speeds were presented in descending order: 2, 1.3, 1, and 0 r.p.s. Two r.p.s. was introduced as maximum speed in view of the greater resistance of the curve to shrinkage. Judgments were obtained from 10 observers.

Results: The results are presented in Table II and Fig. 2. At 1.3 r.p.s. the curves shrink considerably less than does the arc of Experiment I, while further shrinkage occurs at 2 r.p.s. At all speeds, the blunt curve shrinks less than the pointed curve. This difference is reliable at 2 r.p.s. and nearly reliable at 1.3 r.p.s.

The very problem of the nature of the shrinkage, however, can be answered only through introspection. Asked what they saw, all observers reported at the highest speed an irregularly filled-in blotch. Such descriptions as 'blurred square,' 'circular blur,' 'one-inch-high

[1] The writer is indebted to the late Professor Max Wertheimer for having suggested this experiment and for the interest he showed in the study.

TABLE II

SHOWING THE APPARENT LENGTH IN CM. OF (1) A BLUNT AND (2) A POINTED SINE CURVE OF 13 CM. LENTH AND 3.3 CM. AMPLITUDE AT VARIOUS SPEEDS (EXPERIMENT II).
Judgment always in descending order from fast to slow.

	Obs. No.	Rotation Speeds in Revolutions per Second			
		0	1	1.3	2
(1) Blunt sine curve	13	12.2	10.8	8.2	5.3
	14	12.6	10.6	9.4	5
	15	11.8	10.7	8.9	4.9
	16	12.8	12.9	9.2	3.9
	17	14.6	9.9	6.8	4.5
	18	12.7	12.9	8.4	3.9
	19	10.6	9.7	8.5	5.3
	20	14.5	11.3	9.9	5
	21	12.7	10.7	8.2	5.5
	22	12.0	10.9	8.1	5.2
	Average	12.65	11.04	8.56	4.85
(2) Pointed sine curve	13	12.9	9.3	5.8	3.4
	14	11.9	11.3	8.3	3.2
	15	11.6	10.6	3.8	2.6
	16	11.7	12.2	8.2	3.3
	17	12.3	10.7	3.6	3.2
	18	13.7	12.9	10.4	3.7
	19	10.4	8.3	7.4	5.2
	20	14.5	12.3	8.9	4.3
	21	12	10.1	6.6	4.1
	22	11.1	10.2	7.9	4.4
	Average	12.21	10.79	7.09	3.74
Difference Blunt-Pointed	Average			1.47	1.11
	Sigma			±1.77	±.7
	D/Sigma D			2.18	4.20

straight line,' 'like a pretzel,' were given. At the lower speeds, the observers were able to recognize the figure as a sine curve, usually with 2 to 3 peaks. In two instances 3 or 4 and 5 or 6 peaks were reported, the second instance of Metzger's (**22**) phenomenal multiplication of elements in motion.

We take these introspections as evidence that the shrinkage is due to telescoping.

Summary: (1) Shrinkage is due to telescoping. (2) Sine curves shrink less than an arc. (3) A blunt curve shrinks less than a pointed curve.

Experiment III: Straight line at an angle as the moving stimulus.

Purpose: To determine further which quality of a figure is decisive for resistance to shrinkage.

Procedure:

A straight line, 13 cm. long and .5 cm. wide, was placed at its middle point at an angle of 17° with the tangent of a circle, the radius of which was 19.5 cm. At one time the angle was pointing

in the direction of the motion, the next time, in the opposite direction. Judgments were obtained from 10 observers. Only one speed, 1.3 r.p.s., was used.

Results: The results are presented in Table III and Fig. 2. The first angle side was judged 10.9 cm. long, the second 10.6 cm., a difference which is not significant. In comparison with the more structured figure of the sine curve, we have here a less structured figure offering considerably greater resistance to shrinkage. The illuminated surfaces were 6 sq. cm. for the angle side as compared to 7.4 sq. cm. for the sine curves. Thus, greater resistance to shrinkage is also not necessarily related to greater illuminated surface. A common determinant for shrinkage does, however, emerge and is presented in the Discussion.

TABLE III

SHOWING THE APPARENT LENGTH IN CM. OF 13 CM. ANGLE SIDES (EXPERIMENT III) AND TRIANGLES (EXPERIMENT IV) ROTATING AT 1.3 R.P.S.

Obs. No.	Exp. III, 1 (angle side pointed in the direction of movement)	Exp. III, 2 (angle side pointed in the direction opposite to movement)	Exp. IV, 1 (pointed triangle)	Exp. IV, 2 (blunt triangle)
13	10.9	11	11.2	9.2
14	10.7	10.8	10.7	10.5
15	10.9	11.4	9.9	10
16	12.1	11.8	12.1	11.2
17	10.5	9.7	9.3	7.9
18	11	9.6	11.8	10.4
19	10.4	8.6	9.7	9.1
20	11.4	10.6	11.7	10.2
21	10.7	11.7	11.6	9.5
22	10.6	11.1	10.5	11.5
Average....	10.92	10.63±1.00	10.85	9.95

	Differences	C.R.'s
III, 1—III, 2	.29	Assumed not to be significant
III, 1—IV, 1	.07	Assumed not to be significant
III, 2—IV, 2	.68	2.20
IV, 1—IV, 2	.90	2.56

Introspection furnishes further results of this experiment. In preliminary trials the angle side was seen as some sort of a triangle with the angle completed and filled in. In the experiment proper, therefore, the observers were asked to draw what they had seen. All drawings looked like a triangle, the total surface of the seen object thus being actually larger than that of the stimulus. The subjective contribution was in the direction of a more stable figure, inasmuch as the seen triangle provided a base on which the angle side would rest firmly in its path of rotation. This is still further evidence of Gestalt factors in FMP.

Summary: (1) In FMP, angle sides, although smaller, appear larger than sine curves. (2) Evidence for the operation of Gestalt laws in FMP was found.

Experiment IV: Triangle as the moving stimulus.

Purpose: To determine what would be seen if the stimulus were a triangle, similar to those described in the introspections of Experiment III.

Procedure:

A triangle, like those shown in Fig. 3, was used as stimulus. It had a surface of 15 sq. cm., as against 6 sq. cm. of the angle side. Judgments were obtained at 1.3 r.p.s., as in the preceding experiment, and from the same 10 observers. Two settings of the triangle were used: (1) with the pointed end, (2) with the blunt side forward in the direction of movement.

Results: The subjective length obtained for setting 1 was 10.85 cm., for setting 2, 9.95 cm. Individual values are shown in Table III and the averages plotted in Fig. 2. In comparing the triangles with the

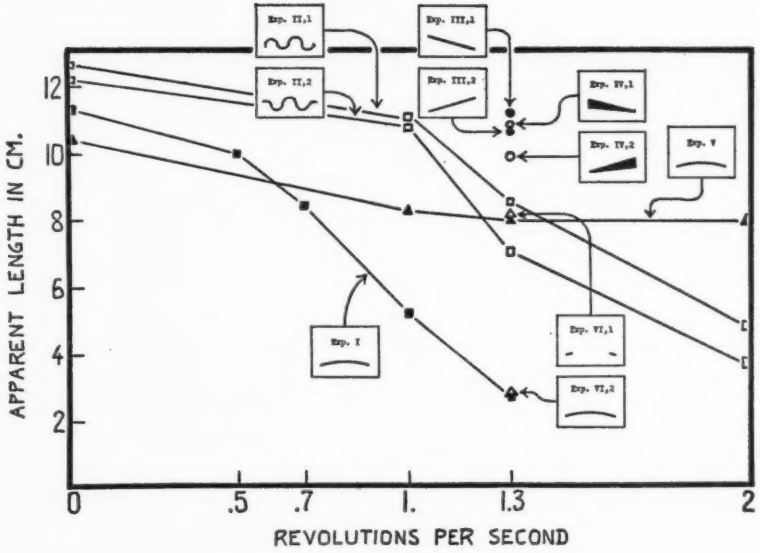

FIG. 2. Results of experiments I–VI.

corresponding angle sides, one may speak of a tendency of the triangles to shrink more, although their surface is $2\frac{1}{2}$ times larger. One of these differences (.07) is not significant, but the other (.90) is nearly so (CR = 2.20). Again, as in Experiment II, greater resistance to shrinkage is not related to greater illuminated surface. The blunt triangle shrinks nearly significantly more (CR = 2.56) than the

pointed. The blunt curve was found to shrink less than the pointed. This apparent contradiction will find its resolution in the Discussion. Introspectively, the same figures were reported from the triangles as from the angle sides, only that the new figures seemed brighter.

Summary: (1) Triangles, although larger, tend to shrink more than corresponding angle sides. (2) A blunt triangle tends to shrink more than a pointed one.

IV. Discussion

(1) *Hypothesis of visual physiological pulsations.*

The first four experiments have shown that: (1) the greater the speed, up to the maximum used, the greater the amount of shrinkage; (2) the perceived shrinkage is due to telescoping; (3) the shape of the stimulus affects the extent of shrinkage (for details see summaries of Experiments II–IV); (4) Gestalt principles are effective in FMP.

Further consideration of point 3 leads to the following exposition. At 1.3 r.p.s. (rate representing judgments on all stimuli) a complete circle is formed in 770 ms. Since in each case used, the length of the stimulus was 1/10 of a circle, the time required to pass a point, or to move its own length, is 1/10 of 770 or 77. ms., or in round numbers 80 ms.

Now let us assume that during this travel period of 80 ms. the stimulus was 'stopped' by stroboscopic photography at 6 equal intervals. This would yield series of pictures as shown in Fig. 3, which series would in actual photography form arcs of 72°.

The 'stroboscopic' series of five stimuli in Fig. 3 are arranged from bottom to top according to their proneness to shrinkage. Inspection indicates that with the plain arc of Experiment I the individual phases overlap completely. With the angle side of Experiment III, individual phases do not overlap at all. Between these two extremes we find degrees of overlapping, occurring roughly in the same order as shrinkage.

In Experiment II the pointed sine curve shrank more than the blunt curve because the former apparently produced the greater overlap; in Experiment IV the blunt triangle shrank more than the pointed, for the same reason. Overlap thus emerges as the common determinant of shrinkage.

By what mechanism can overlap be related to shrinkage? Let us consider the plain arc. In stroboscopic photography the developed film would show 6 degrees of light exposure, with the center receiving 6 times as much light as the two extremes, and 5 stepwise gradations in between. What would take place on the photographic plate can properly be assumed to hold for the retina, with the difference that its

exposure is distributed in the shape of an isosceles triangle instead of a histogram. The assumption that light stimulation of the retina adds up in this fashion is justified, since the Bunson-Roscoe law holds in the human eye up to 200 ms. (Troland, **25**, p. 671). In such triangular distribution of light exposure of the retina, apparently only that extension is seen which receives maximum stimulation, i.e., continuous stimulation during the time interval in question. The other parts become eclipsed, possibly through contrast effect, accounting for the shrinkage.

With changes in the hypothetical duration of the stimulus process of 80 ms., changes in light distribution would be as follows: (1) Within

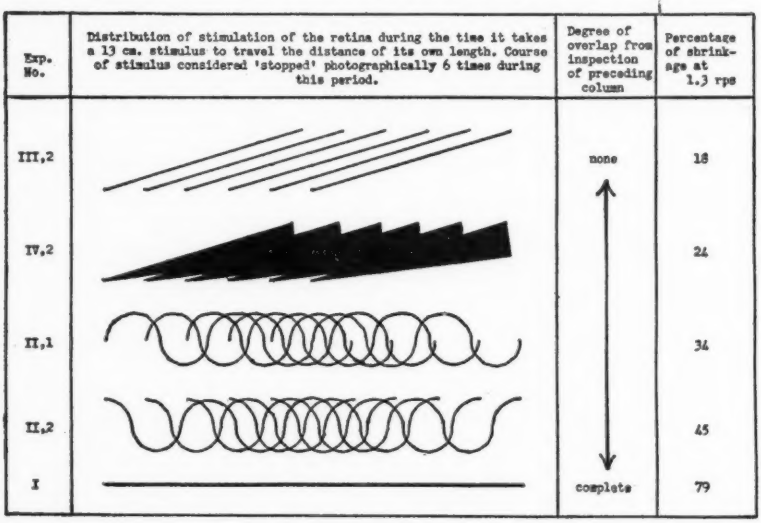

FIG. 3. Showing distribution of retinal stimulation in relation to degree of overlap and percentage of shrinkage.

less than 80 ms., distribution would take the form of a plateau, which would be the longer and lower, the shorter the duration of the process. In the extreme case, where this would last only one instant, there would be no plateau, and the brief maximum stimulation would coincide with the length of the stimulus. This is the situation in Experiment III with the angle side, where we find that the perceived object is practically of the same length as the stimulus. (2) If the stimulus process lasted beyond 80 ms., the plateau would become increasingly longer, with initial ascent and final descent becoming proportionately insignificant. Under these conditions shrinkage should not be expected.

Actually, the stimulation in our experiments was continuous and still the existence of shrinkage has been demonstrated. It therefore becomes necessary to assume that physiological intervals break up the physical continuity, thereby creating the same physiological situation as would the hypothetical 80 ms. stimulation period. Thus, we advance the hypothesis: *the visual mechanism is active for only a certain period, which is followed by another period of inactivity; in other words, the visual mechanism functions in pulsations.*

Such a hypothesis of visual pulsations has, in recent years, received strong physiological support through the electroretinogram studies of Bartley. He found several instances where deviations of the subjective experience from the objective stimulus situation could be related to "an intrnisic periodicity in the visual pathway somewhere" (**4**) or to some pulsations in the optic nerve discharge (**6**). The first deduction was made from the Brücke or Bartley effect, the second, from observations in recurrent vision and records of the optic nerve discharge. A similar deduction was made from a third experiment in which subjective flicker rate was compared with objective flash rate (**3**).

Previously, Fröhlich (**12**) had made "the unqualified assumption that the sense organs . . . respond to stimuli with rhythmical excitations" (p. 45). This he based on the general attribute of all living substance to respond to the most diverse kind of stimuli with a series of excitation waves (p. 37).

In Bartley's experiments rhythmicity was present in two of the stimulus conditions, while in the third, recurrent vision, the stimulus was a brief flash; subjective rhythmicity was found in all three experiments. In our experiments, rhythmicity was present neither in the stimulus situation nor in the subjective situation, but both were continuous. Nevertheless, a hypothesis of pulsations in the optic mechanism offers the best explanation of our findings. In our experiments we would then have, using Fröhlich's (**12**, p. 27) terminology, a *rhythm of the first order* "with which any living substance may respond to a [non-rhythmic] stimulus" (on the physiological level), in Bartley's experiments, a *rhythm of the second order* "with which a living substance responds to a stimulus which is rhythmical itself."

Since according to our theory pulsations transform real movement into discrete physiological 'stills,' and since nevertheless we perceive movement, it follows that the 'stills' would enter perception re-translated into movement, even as the stills in moving pictures (and all apparent movement) are translated into perceptual movement. Perception of real movement would thus rest on the same principle as perception of apparent movement, with the exception that the 'stills' in the former would be of physiological rather than physical origin.

Koffka (**21**, p. 281) states: "It has been proved beyond a doubt that as far as psychophysical dynamics are concerned there is no difference between stroboscopic and 'real' motion." The present considerations would carry this theory one step further, namely, that stroboscopic motion is physiologically more elementary.

These views are in accord with an inference made by Smith and Kappauf (**24**) from a study in which they succeeded in eliciting optic nystagmus in cats in response to apparent movement stimulation. They believe "that the physiological representation of real movement . . . is also a series of discrete neural patterns."

(2) *Calculation of a constant.*

If the hypothesis of visual physiological pulsations is correct, we should be able to calculate from the data in Experiment I a time constant which would correspond to the duration of one pulsation, the pulsation time. This is attempted in the following.

If at .5 r.p.s. it takes the apparatus disk 2000 ms. to pass a single retinal point (RP), and it takes the 13 cm. stimulus arc (which is 1/10 of the circumference of the disk) 200 ms. Like calculations for each speed are found in Table IV, Column 3.

From the rate (Column 1) and the apparent length of the arc (Column 4), one can calculate how long it would take the apparent length to pass one RP (Column 5). Column 6 gives the difference between Columns 3 and 5. This difference increases with speed from 46 ms. to 61 ms. We shall take the average value of 55 ms. as basic, representing a constant time factor present at all four speeds. The gradual increase to 61 ms. will be briefly discussed under the results of Experiment V.

The time constant, being the difference between the duration of *real* movement over a single RP and the duration of *perceived* movement over a single RP, expresses the duration during which *no perceived* movement occurs at a single RP, although real movement does occur.

During the actual phenomenon, however, we are dealing not with a single RP but with a series of RP's. The occurrence over a series of RP's is described in Fig. 4, which is based on the measures of Table IV. In Fig. 4 the Y-axes indicate time in ms., while the X-axes indicate two measures of distance: (1) the distance in cms. travelled by the stimulus, and (2) the extension of the stimulation of the retinal surface, expressed in hypothetical RP's. Speeds are plotted from Table IV, Column 3. The distances between the speed lines parallel to the X-axes represent the length of the stimulus arc. The speed lines at the left represent the function of *withdrawal of stimulation*

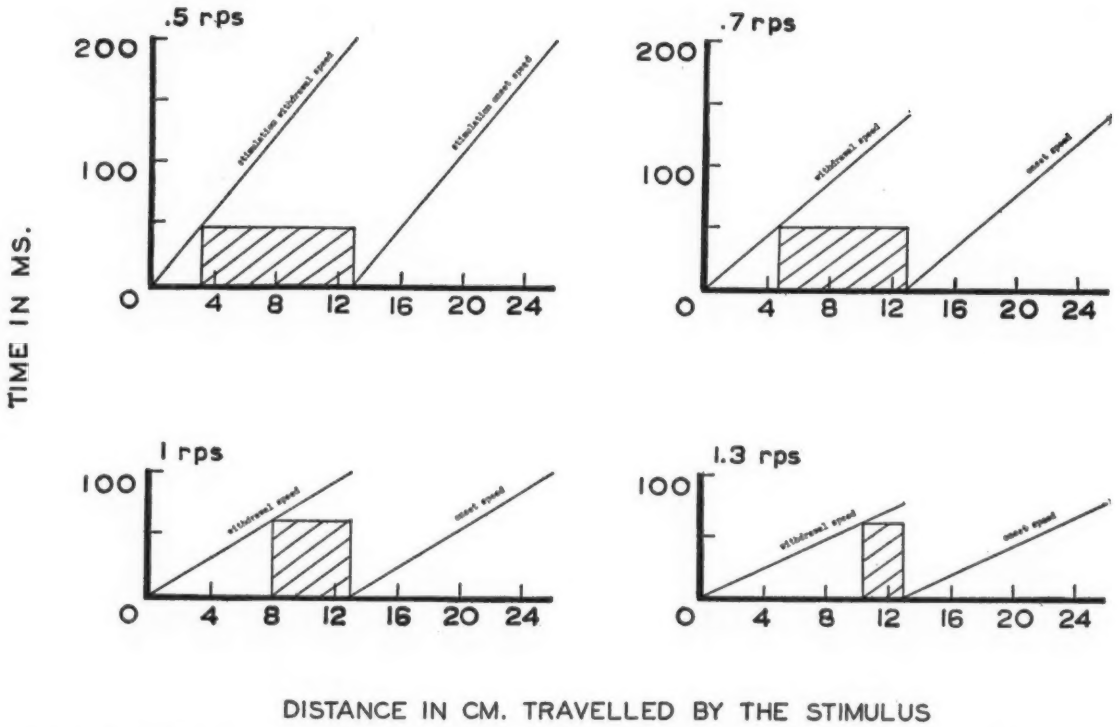

FIG. 4. Showing distribution of retinal stimulation during the various speeds of Experiment I, based on the measures of Table IV.

from the various RP's. (At .5 r.p.s. the left speed line indicates that stimulation was withdrawn from RP 0 immediately; from RP 3, after 46 ms.; and from RP 13, after 200 ms.) The speed lines at the right represent the function of *onset of stimulation* of RP's beyond the RP 13.

We have found above that the time constant of 55 ms. expresses the duration during which no perceived movement occurs at a single RP. In Fig. 4 we see the stimulation conditions of a series of RP's (0 to 13) during the time constant. By plotting at .5 r.p.s., for example, the 46 ms. (time constant) line, we see that it represents the duration during which no withdrawal of stimulation has occurred beyond RP 3, and during which all new stimulation has occurred

TABLE IV

SHOWING TIME REQUIRED FOR AN ARC OF THE REAL LENGTH AND AN ARC OF THE APPARENT LENGTH TO PASS A SINGLE RETINAL POINT (RP) AT THE VARIOUS RATES OF SPEED, AND THE DIFFERENCE BETWEEN THESE TWO DURATIONS

1	2	3	4	5	6
R.p.s.	Length in cm. of real arc	Duration in ms. of real movement over one RP	Length in cm. of apparent arc	Duration in ms. of perceived movement over one RP	Difference between columns 3 and 5. Duration in ms. during which no perceived movement occurs over one RP, although actual movement does occur
.5	13	200	10	154	46
.7	13	143	8.4	92	51
1	13	100	5.2	40	60
1.3	13	77	2.7	16	61

beyond RP 13. This distance from RP 3 to RP 13 over which no change in stimulus conditions did occur during 46 ms. corresponds to the length of the perceived moving stimulus, which is 10 cm. In other words, that much of the moving stimulus is seen which stimulates the retina uniformly during 46 ms. At .7, 1, and 1.3 r.p.s., corresponding relationships are found in Fig. 4. In each instance, the retinal extension for which no change in stimulus conditions occurred during the time constant and which received uniform maximum stimulation during that time, corresponds to the length of the perceived object. The rest of the stimulation is eclipsed, possibly through contrast effect.

We have shown, then, that the time constant of 55 ms. is directly related to the perceived length. In terms of the hypothesis of visual pulsations, the constant would correspond to the pulsation time, or rather to the 'on' response of the pulsation. Regarding the duration of the 'off' response, no indication is available.

Where could a constant of 55 ms. fit in existing knowledge? We have found six instances where a similar value was derived: (1) Fröhlich (**13**, p. 58) found a visual sensation-time of 40–150 ms., depending on the light intensity used. (In the present experiments the effects of change in light intensity were not investigated.) (2) Vierordt (**26**, pp. 123 ff.) thought that perception was composed of single impressions which had an average duration of 41 ms. (3) Modern moving pictures are shown at the rate of 20 frames per sec., which is 50 ms. per frame including the pause. (4) For the phi phenomenon the best appearance of movement occurs at an interval of about 60 ms. (Woodworth, **29**, p. 682). (5) In recurrent vision, the initial short dark interval lasts on the average about 40 ms. and is followed by the first positive after image, or Hering's image, which lasts about 50 ms. (Bartley, **6**). (6) Regarding flicker frequency, Bartley (**5**, p. 124) found that with increasing illumination the rate of last seen or marginal flicker remains constant at a frequency of about 20 per sec., while objective frequency increases from below 20 to nearly 60 per sec. Here again a period of approximately 55 ms. is involved.

It may well be that the above values and our own constant are all related to the same mechanism, and it is hoped that the present findings will be an aid in the ultimate synthesis.

V. Additional Experiments (V–VII) and Results

In the Discussion we have assumed that the length of the perceived object is determined by the length of maximal constant light distribution on the retina (complete overlap of stimulation) during a limited interval of physiological pulsation. The three additional experiments were designed to test the first part of this assumption.

Experiment V: Replacement of real movement by apparent movement.

Purpose: In real movement, we have seen that maximal constant light distribution on the retina during the pulsation time of 55 ms. is reduced in accordance with the speed of movement, and that the perceived length shrinks at the same rate. If light distribution really causes the shrinkage phenomenon, then a change in the former should result in a corresponding change in the latter. A change in light distribution can be produced through replacing real movement by apparent movement. In apparent movement, the stimulus does not move, and, consequently, the length of maximal constant light distribution on the retina (during the physiological pulsation) always corresponds to the stimulus length, irrespective of the speed of the apparent movement. Thus, in apparent movement, the seen length should

always be equal to the length of the stimulus. It was the purpose of the present experiment to test this prediction.

Procedure:

An apparatus corresponding with the original was constructed on the principle of a moving electric sign. It showed a translucent white circle (completing the arc of Experiment I) on a black cardboard. In front of the center of the circle the original black box with the adjustable white line (see box B, Fig. 1) was mounted, permitting measurement of the seen length. Behind the circle 10 groups of three small bulbs were mounted so that each group, when lit, illuminated 1/10 of the circle, i.e., an arc of 13 cm. length. To create apparent movement a wind-up phonograph motor was used, in which the turntable was replaced by a stationary plate of insulating board. On this board 10 contact plates were arranged at intervals of their own width. Attached to the drive of the motor was a wooden arm with a brush contact which contacted the plates as it rotated. Through proper wiring the 10 parts of the arc could thus be illuminated in succession.

The motor was calibrated for 1, 1.3, and 2 r.p.s., which in addition to zero r.p.s., were the speeds used in this experiment. Judgments were obtained from eight observers.

Results: The results are presented in Table V and Fig. 2. At zero speed the apparent length was 10.4 ± .95 cm. which compares with

TABLE V

Showing Apparent Length in Cm. of a 13 Cm. Arc in Apparent Movement at Various Speeds (Experiment V)

Obs. No.	Rotation Speeds in Revolutions per Second				Arrow indicates sequence of stimuli
	0	1	1.3	2	
23	10	9.3	8.9	9.4	←
24	12.3	9.1	8.4	7.5	←
25	11.3	8.7	8.4	8.4	→
26	10.3	8.1	7.8	7.8	→
27	8.9	6.7	6	6.5	←
28	10	7.7	7.5	7.5	←
29	9.9	8.4	8.7	8.7	→
30	10.5	8.4	8.4	8.5	→
Average	10.4±.95	8.3±.77	8.±.87	8	

Average 0 r.p.s. vs. average 1 r.p.s.: D/Sigma D = 8.

an apparent length of 11.3 ± 1.75 cm. for zero speed in Experiment I. The difference between the two measures, while not reliable (CR = 1.5), is interesting to account for: in the present experiment there was no contrast effect in the fast-slow sequence due to the greatly limited shrinkage.

At 1, 1.3, and 2 r.p.s., averages of 8.3, 8, and 8 cm. respectively were obtained. Thus, in apparent movement, increase in speed beyond one r.p.s. does not produce further shrinkage.

The difference of 2.1 cm. in subjective length, between 0 r.p.s. and 1 r.p.s., is, however, highly reliable (CR = 8). Since the stimulus distribution is the same for these two speeds, as for all other speeds, the shrinkage must be attributed to a psychological factor in the per-

ception of movement. While this factor distinguishes between standing still and fairly fast movement, it does, apparently, not distinguish between further increases in speed.

If movement itself, irrespective of light distribution, accounts for a shrinkage of 2.1 cm., total shrinkage in all the preceding experiments must be regarded as the product of physiological shrinkage and psychological shrinkage. Inspection of Fig. 4 shows that, with everything else remaining constant, the counterpart of an increase in shrinkage would be increased pulsation time. Thus, if we could partial out in Experiment I the increased shrinkage due to the psychological factor, we should arrive at lower pulsation times. In future studies this might be attempted; it may be that the gradual increase in pulsation times in Column 6 of Table IV can be attributed to the psychological factor.

Summary: (1) In apparent movement of the arc, where the length of maximal constant light distribution always corresponds to the stimulus length, little shrinkage is found, and there is no further increase in shrinkage with increase in speed. (2) Since the little shrinkage found cannot be attributed to stimulus distribution, a psychological component in the general shrinkage phenomenon is indicated.

Experiment VI: Replacement of the moving arc by the beginning- and end-points of the arc.

Purpose: Experiment III (the angle side) has already shown that without stimulation overlap there is practically no shrinkage. The purpose of the present experiment was to test this relationship once more, with different conditions. In Experiment III no retinal point was stimulated more than once, in the present experiment all retinal points are re-stimulated. The successive stimulations are not continuous for a given time interval, however; rather they are separated by 65 ms. at 1.3 r.p.s., and stimulation as well as re-stimulation last only 6 ms. each.

Procedure:

The original apparatus was used for two series: (1) 11 cm. in the center of the original 13-cm. stimulus arc were darkened, (2) they were not darkened. The observers were the same as in Experiment V, the speed was 1.3 r.p.s. The illumination came from a source of 500 watts because with the 100-watt illumination of the original experiment the two rotating points appeared too dim to permit convenient judgments.

Results: The results are presented in Table VI and Fig. 2. The value of 2.74 cm. for series 2 is virtually the same as the corresponding value in Experiment I. The value of 8.16 cm. for series 1 is virtually the same as the values found in apparent movement (Experiment V), and the small shrinkage here, as in Experiment V, may be attributed to a psychological component. The difference of 5.42 cm. between

the values for the two series is highly significant (CR = 7.53). The shrinkage of 8.16 cm. in the judgment of series 1 is reliably greater than that of 10.63 cm. in Experiment III (CR = 3) and may be attributed to the difference between the figures. The two points describe but one circular line, as in apparent movement, whereas the angle side describes a track corresponding to that left by the blade of a snow plow.

Summary: In the rotation of two points, where overlap of stimulation is practically ruled out, shrinkage is reduced to that which can be attributed to its psychological component.

Experiment VII: Changing the length of the moving arc.

Purpose: We found in Experiment I that a 13 cm. arc moving at 1.3 r.p.s. shrinks subjectively to 2.7 cm. The question to be answered here is: Would a 26 cm. arc under the same conditions shrink proportionately 20.6 cm., or would the shrinkage of 10.3 remain constant? According to our assumption that the seen length is determined primarily by the extent of maximal constant light distribution on the retina during one visual pulsation, the latter should be expected. This can easily be seen from Fig. 4, where an added 13 cm. would, at any speed, show itself directly in a corresponding lengthening of the region of maximal constant light stimulation. The purpose of this experiment was then to test this prediction.

TABLE VI

SHOWING APPARENT OVER-ALL DISTANCE BETWEEN TWO POINTS (ORIGINAL 13-CM. ARC WITH MIDDLE 11 CM. DARKENED), AND APPARENT LENGTH OF 13-CM. ARC, BOTH ROTATING AT 1.3 R.P.S. (EXPERIMENT VI). Judgment of two-point distance always preceded judgment of arc length

Observer Number	Two Points	13 Cm. Arc
23	9.5	4
24	11.9	2.9
25	7.6	2.5
26	6.5	2.4
27	7.8	3.3
28	8.3	1.9
29	6.8	1.4
30	6.9	3.5
Average.....	8.16±1.68	2.74

Average two points vs. average 13-cm. arc: D/Sigma D = 7.53.

Procedure:

A disk was cut for the original apparatus in which the size of the arc could be varied from 6.5 to 26 cm. Judgments were obtained from 10 observers with arc settings at 6.5, 13, 16.25, 19.50, and 26 cm., at a speed of 1.3 r.p.s.

Results: The results are presented in Table VII. They show that the 13 cm. arc shrinks to 3.34 cm., the 26 cm. arc to 17.26 cm. The shrinkage (difference between real and apparent size) is 9.66 cm. for the former and 8.74 for the latter. The difference between these two

values is not significant, the CR being .85. Similar values were found for the intervening sizes. Shrinkage then is not proportional to the length of the arc, but rather a constant for a given speed.

While shrinkage does not increase with the size of the arc, the variability of the shrinkage does: SD of shrinkage for the 13 cm. arc is ± 1.86, for the 26 cm. arc, ± 3.67, almost exactly double.

Regarding the shrinkage value obtained from the 6.5 cm. arc, it must necessarily be less than the other values obtained, since the stimulus cannot shrink beyond its length.

TABLE VII

SHOWING APPARENT LENGTH IN CM. OF ARCS OF VARIOUS SIZES ROTATING AT 1.3 R.P.S. (EXPERIMENT VII)

Obs. No.	Length of Arc in Cm.					Arrow indicates sequence of stimuli
	6.50	13	16.25	19.50	26	
31	1.5	2	11	13.9	19	→
32	1.3	2.5	5.3	9.3	12.7	←
33	1	1.6	7.1	8.9	15.4	→
34	1.1	3.7	8.5	13.6	19	←
35	1	2.9	4.3	9.6	19	→
36	3.6	6.9	10.7	15.5	20	←
37	.5	2.4	6	7.6	10.9	→
38	1.5	3.1	5.1	8.2	18	←
39	1.1	1.5	3.5	7.8	14.6	→
40	4.1	6.8	12.5	16.4	24	←
Mean	1.67	3.34	7.40	11.08	17.26	
Real Minus Apparent Size (Shrinkage)	4.83±1.13	9.66±1.86	8.85±2.96	8.42±3.21	8.74±3.67	

Shrinkage 13 cm. arc vs. 26 cm. arc: D/Sigma D = .85

Summary: As previously shown, that extension of the retina which does *not* receive maximal constant light stimulation during one visual pulsation determines the part of the stimulus which is not seen. This extension remains the same irrespective of the size of the stimulus. Thus we find that with increase in size, shrinkage remains constant, although the variability of the shrinkage increases roughly in proportion with the increase in stimulus length.

VI. SUMMARY AND CONCLUSIONS

A phenomenon has been presented which consists in the fact that an illuminated arc of 36°, rotating at less than fusion speed, and observed with fixed eyes, appears to shrink to a fraction of its actual length. This phenomenon is linked to related observations in the literature.

Various aspects of the phenomenon were investigated, and it was found: (1) The shrinkage is the greater, the greater the speed (within the limits of the present investigation) (Experiment I). (2) The shrinkage is due to telescoping rather than to a dropping out of the beginning or the end of the stimulus (Experiment II). (3) A sine curve shrinks less than an arc (Experiment II). (4) An angle side shrinks less than an arc (Experiment III). (5) Gestalt laws are operative in the phenomenon (Experiment III). Greater surface of the stimulus does not necessarily mean less shrinkage, a triangle tending to shrink more than one of its sides (Experiment IV).

In the Discussion, shrinkage was shown to be a function of the degree of overlap of retinal stimulation, provided the existence of visual pulsations is assumed. The assumption of pulsations is supported by the work of Bartley. A theory of visual pulsations would carry the Gestalt theory of motion perception one step further, namely, that stroboscopic motion perception is physiologically more elementary than 'real' motion perception.

The duration of one pulsation was calculated from data of Experiment I to be 46–61 ms., and was compared to similar values previously found significant in the field of visual perception.

Three additional experiments (V–VII) brought further evidence that shrinkage is actually a function of the degree of overlap of retinal stimulation during the assumed period of visual pulsation.

Of the aspects not covered by this paper, the two most obvious ones are: the effect of increased distance of the observer from the apparatus, and the effect of change in illumination. Regarding the second aspect data are at hand to indicate that shrinkage is facilitated by increased illumination.

(Manuscript received November 19, 1943)

Bibliography

1. Ansbacher, H. Perception of number as affected by the monetary value of the objects. *Arch. Psychol., N. Y.*, 1937, No. 215. Pp. 88.
2. Ansbacher, H. Further investigation of the Harold C. Brown shrinkage phenomenon; a new approach to the study of the perception of movement. *Psychol. Bull.*, 1938, **35**, 701.
3. Bartley, S. H. Subjective flicker rate with relation to critical flicker frequency. *J. exp. Psychol.*, 1938, **22**, 388–394.
4. Bartley, S. H. Subjective brightness in relation to flash rate and the light-dark ratio. *J. exp. Psychol.*, 1938, **23**, 313–319.
5. Bartley, S. H. *Vision; a study of its basis.* New York: Van Nostrand, 1941. Pp. xv + 350.
6. Bartley, S. H. The features of the optic-nerve discharge underlying recurrent vision. *J. exp. Psychol.*, 1942, **30**, 125–135.
7. Boring, E. G. *Sensation and perception in the history of experimental psychology.* New York: Appleton-Century, 1942. Pp. xv + 644.
8. Brown, J. F. The visual perception of velocity. *Psychol. Forsch.*, 1931, **14**, 199–232.
9. Ehrenstein, W. Versuche über die Beziehung zwischen Bewegung und Gestalt Wahrnehmung. II. *Z. Psychol.*, 1925, **97**, 161–173.

10. EHRENSTEIN, W. Versuche über bevorzugte Bedingungen der Eindringlichkeit bewegter optischer Reize. *Psychol. Forsch.*, 1926, **7**, 257–259.
11. EHRENSTEIN, W. Untersuchungen über Bewegungs- und Gestaltwahrnehmung. IV. *Z. Psychol.*, 1936, **139**, 345–359.
12. FRÖHLICH, F. W. Über die rhythmische Natur der Lebensvorgänge. *Z. allgemeine Physiol.*, 1912, **13**, Referate 1–48.
13. FRÖHLICH, F. W. Über die Messung der Empfindungszeit. *Z. Sinnesphysiol.*, 1923, **54**, 58–78.
14. FRÖHLICH, F. W. Über die Methoden der Empfindungszeitmessung im Gebiet des Gesichtssinnes. *Arch. ges. Physiol.*, 1925, 120–134.
15. FRÖHLICH, F. W. *Die Empfindgungszeit. Ein Beitrag zur Lehre von der Zeit-, Raum- und Bewegungsempfindung.* Jena: G. Fischer, 1929. Pp. x + 366.
16. GERTZ, H. Untersuchungen über Zöllner's anorthoskopische Täuschungen. *Skand. Arch. Physiol.*, 1900, **10**, 53–73.
17. HECHT, H. Die simultane Erfassung der Figuren. *Z. Psychol.*, 1924, **94**, 153–194.
18. HELMHOLTZ, H. v. *Handbuch der physiologischen Optik.* (2nd ed.) Hamburg & Leipzig: Voss, 1896. Pp. 1334.
19. KELLOGG, W. N. An improved model of McDougall's after-image apparatus. *Amer. J. Psychol.*, 1929, **41**, 119.
20. KOFFKA, K. Die Warhnehmung von Bewegung. In: BETHE, A. *Handb. norm. path. Physiol.*, 1931, **12**, Part 2, 1166–1214.
21. KOFFKA, K. *Principles of Gestalt psychology.* New York: Harcourt, Brace & Co., 1935. Pp. 720.
22. METZGER, W. Über die Vorstufen der Verschmelzung von Figurenreihen die vor dem ruhenden Auge vorüberziehen. *Psychol. Forsch.*, 1926, **8**, 114–221.
23. ROTHSCHILD, H. Untersuchungen über die sogenannten anorthoskopischen Zerrbilder. *Z. Psychol.*, 1922, **90**, 137–166.
24. SMITH, K. U., & KAPPAUF, W. E. A neurolgoical study of apparent movement. *J. gen. Psychol.*, 1940, **23**, 315–327.
25. TROLAND, L. T. Visual phenomena and their stimulus correlation. In: MURCHISON, C. *A handbook of general experimental psychology.* Worcester, Mass.: Clark University Press, 1934. Pp. 653–703.
26. VIERORDT, K. *Der Zeitsinn nach Versuchen.* Tübingen: Laupp, 1868. Pp. 191.
27. VOLK, J. Tachistoskopische Untersuchungen. *Z. Psychol.*, 1927, **102**, 57–106.
28. WENZEL, E. L. Die sukzessive Erfassung der Figuren. *Z. Psychol.*, 1926, **100**, 289–324.
29. WOODWORTH, R. S. *Experimental psychology.* New York: Holt, 1938. Pp. xi + 889.
30. ZÖLLNER, F. Über eine neue Art anorthoskopischer Zerrbilder. *Ann. Phys., Pogg. Ann.*, 1862, **117**, 477–484.

SPECTRAL SATURATION AND ITS RELATION TO COLOR-VISION DEFECTS [1]

BY ALPHONSE CHAPANIS

Yale University

Introduction

Color vision theorists have always been interested in the psychophysical relationships between the physical attributes of radiant energy (wave-length, intensity and purity) and the three psychological attributes of color (hue, brilliance and saturation [2]) in individuals who possess defective color vision since it is generally agreed that any adequate theory of color vision should account for these deviations. Attempts to integrate the phenomena of color blindness with normal data have, however, been hampered greatly by the lack of precise quantitative information relating to certain color vision characteristics of the color defective.

One of the important problems still virtually unexplored is that of the saturation of the spectrum for the color blind. Hecht and Shlaer (**12**) have indicated recently that saturation differences in the spectrum may be fundamentally more important than the wave-length discrimination function, since the former can entirely account for the latter in the dichromatic eye. This finding suggests that further research on the saturation function in complete and incomplete dichromatism might yield data of some importance to color theory, especially since existing theories have more adequate explanations for the hue and brightness of the spectrum than for saturation.

The investigation reported here is a determination of the relationship between the degree of color blindness and the saturation thresholds for 19 spectral hues. The measure of saturation threshold used is the reciprocal of least perceptible colorimetric purity. This measure is only one of several which might have been employed; its chief advantage is that it has been widely used in studies on normal *S*s so that there are extensive data against which to compare

[1] This article constitutes part of a dissertation submitted in July 1942 to the Faculty of the Graduate School of Yale University in partial fulfillment of the requirements for the degree of Doctor of Philosophy. The writer is indebted to Dr. Walter F. Grether, Dr. Walter R. Miles, and Dr. Carl I. Hovland for their assistance in numerous technical matters, and to Dr. Donald G. Marquis for his critical reading of the manuscript.

[2] For definitions of the technical terms used in this paper the reader is referred to Troland (**24**).

results on the color blind. Least perceptible colorimetric purity may be defined as the ratio of the luminosity of the dominant hue to the luminosity of a mixture of white plus hue, where the mixture is judged to be just noticeably different from white or gray in hue, i.e., $p = \frac{L_\lambda}{L_W + L_\lambda}$. The reciprocal of this value, $\frac{1}{p} = \frac{L_W + L_\lambda}{L_\lambda}$, is used only for the reason that it conveniently represents a low saturation by a low value and a high saturation by a high value. Since the computation of this ratio requires a measure of the brightnesses of the various spectral hues for each observer, relative luminosity curves were also obtained.

Six *S*s with varying degrees of color defect were used in the experiment. Two were true dichromats, one a protanope and the other a deuteranope, while the remaining four were incomplete dichromats, three deuteranomalous and one protanomalous. The results of two normal observers serve as controls.

There are in the literature only three earlier studies on the saturation function in color blindness. In 1879 von Kries and Küster (**25**) reported that the spectrum of the dichromat consists of two hues, one on each side of the neutral point, varying only in saturation. They showed (1) that a protanope would never confuse a monochromatic green and yellow equated in brightness, and (2) that he would match them completely as soon as a little white light was added to the yellow. Other pairs of colors gave similar results as long as (1) both were on the same side of the neutral point, and (2) the white was added to the monochromatic hue farthest from the neutral point. Geissler (**5**), in 1913, reported incidentally the first saturation thresholds ever obtained on a color blind observer. He found that this *S*, as compared with nine normal observers, required significantly greater amounts of hue in mixtures of hue and gray before the mixtures were called just noticeably different from gray. Hecht and Shlaer (**12**) quantified the results of von Kries and Küster by showing exactly the portions of the spectrum which a protanope would match against varying proportions of white plus 630 mμ and of white plus 440 mμ. They also indicated that this result was derivable from the data on the dichromatic color mixture matching of the spectrum and that it would account for the wave-length discrimination of the dichromat.

Apparatus

The spectral apparatus consisted of twin monochrometers[3] of the same basic design as that described by Grether (6). As will be seen from the diagram of monochrometer unit 1 (Fig. 1),

[3] The basic monochrometer units were loaned by Dr. Robert M. Yerkes of the Yale laboratories of Primate Biology.

XUM

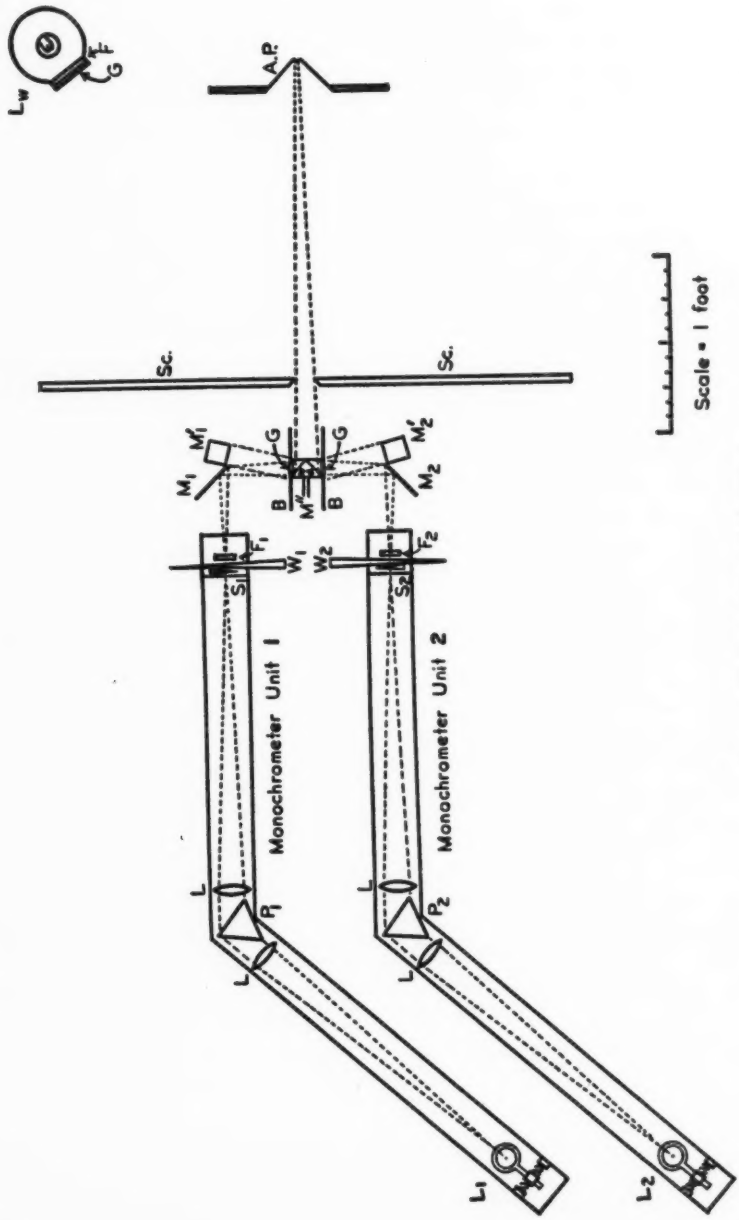

FIG. 1. Diagram of the optical system.

white light from a straight filament lamp, L_1, was resolved into a spectrum by a flint glass prism, P_1. A slit, S_1, at the plane of focus of the spectrum, passed a narrow band of wavelengths which could be altered by means of a micrometer screw. The latter shifted the position of the source lamp and thus changed the position of the spectrum falling on the slit. The slit was kept at a constant width of 0.020 inches.[4] The spectral beam at 500 mμ was 4 mμ wide with this slit width.

Brightness of the spectral colors could be varied by means of a neutral tint wedge, W_1 (transmission 1 to 1/10th), and balance wedge used in conjunction with supplementary 1/10th and 1/100th transmission neutral tint filters, F_1. The wedges and neutral tint filters were gelatine cemented in B glass and were made up and calibrated by the Eastman Kodak Company. The beam of spectral light, upon passing through the slit and filters, was deflected 90° by a first surface silvered mirror, M_1, passed through a diffusing glass consisting of two finely etched surfaces, G, and deflected again by another mirror, M'', which constituted one-half of the test area. The other half of the test area was illuminated by a beam of light from the other monochrometer. The two beams traversed equal distances, one path being a mirror image of the other.

White light was secured from a 200-watt projection lamp placed directly above the test area but carefully shielded from the latter. Light from this lamp passed through a Corning 'Daylite' filter No. 590, a diffusing surface of etched glass, wedge diaphragm, and two mirrors to illuminate the same diffusing glass on which the spectral light fell. Only the last two mirrors, M'_1 and M'_2, of this optical system are shown in Fig. 1. The same lamp furnished white light to both sides of the area; the filter, diaphragm, and mirror systems were duplicated for both sides. When the lamp was operated at 119 volts A.C., the combination of the lamp, filter, and ground glass yielded an energy distribution approximating 5,000° K,[5] the standard selected for white light.

The test area was viewed through an opening 1.25 in. in diameter in a large white screen, *Sc* (three feet square), placed six in. in front of the area. The front surface of the screen was painted with Luminall Paint, a dull white paint with high reflectance, and was illuminated by a flood light placed to one side and behind the observer. The flood light consisted of a lamp, filter, and diffusing glass identical with that of the white light source used to illuminate the test area. Both white lights were operated from the same 119 volt circuit.

The observer viewed the screen and test area through an artificial pupil three mm. in diameter. The screen and test area were 22 and 28 in. respectively from the artificial pupil. At that distance the test patch subtended a visual angle of 3° 15′ and was seen as a fairly homogeneous field divided vertically by a thin black line into two semicircular areas. The test area appeared to be in the same plane as the screen. The front surface of the screen was kept at a constant brightness of approximately 0.30 apparent foot-candles (a retinal illumination of about 7.5 photons). During actual testing all room lights were extinguished.

Two imperfections in the apparatus concern the distribution of light over the test area and its surround. Since the white light source which flooded the screen was situated on one side of the observer, the illumination was somewhat greater on that portion of the screen nearer the light. This unevenness was never noticed and was not as serious as the unevenness of illumination on the test area. The latter arose from the fact that spherical lenses were used in the optical system of the monochrometers. This unavoidably resulted in spectral hues which were brighter in the center than at the top and bottom of the area. Most *Ss* remarked on this unevenness, but all were instructed to base their comparisons on the appearances of the center portions of the test area. White light flooding the test area was quite uniformly distributed.

Procedures

The procedures were planned around three important considerations:

(1) Precautions were taken to insure that *Ss* understood the kinds of discriminations they were to make. Training series were always given before luminosity and saturation measurements

[4] Technical considerations relating to the exit slit width and the purity of the entire spectrum for this slit width will be found in the original thesis (3).

[5] This calibration was made by Dr. W. E. Forsythe of the General Electric Company. Actually the energy distribution contained a little too much green, but for purposes of the experiment, this deviation is probably not significant.

XUM

were begun. This was especially necessary because the dichromats, and two of the anomalous observers, were unable to distinguish between brightness and color differences.

(2) Careful consideration was given to the problem of fatigue. Each experimental session was made as short as possible, rest periods were allowed as often as requested, and a relaxation period of several minutes was enforced after every hour of experimentation. *S*s were encouraged to look away for a while before making a final decision on a color or brightness match. The liberal use of rest periods allowed time for at least a partial recovery from the rapid chromatic adaptation known to be characteristic of the anomalous (**20**).

(3) Methods which would give satisfactory results in the least possible time were used. A complete series of measurements required about 30 hours extending over at least 10 days. It was difficult to secure active coöperation from the *S*s for any longer periods.

Relative luminosity was determined by a heterochromatic brightness matching method. A gray of 0.350 apparent foot-candles (or of 0.104 apparent foot-candles for the extremes of the spectrum) was put into one-half of the test area and a spectral hue in the other. *S*s were instructed to ignore the color difference and to decide when the two halves matched in brilliance. Brilliance of the spectral hue was changed by the *E*. Readjustments were permitted if the match did not appear valid after a short rest.

During each luminosity session four readings were taken at 10 mμ intervals along the spectrum, except between 550 mμ and 580 mμ where they were taken at 5 mμ intervals. Before taking each set of four measurements the *S* was instructed to watch the test area while the *E* slowly varied the brilliance of the hue between extremes of noticeable inequality. This procedure helped *S*s to maintain a fairly constant criterion of brightness equality. Readings at each spectral point were started with the hue alternately darker and brighter than the gray. The order of procedure through the spectrum, i.e., from red to blue or vice versa, was alternated for each *S* on four successive days.

Saturation measurements were taken at the following spectral points: 470, 480, 490, 495, 500, 505, 510, 520, 540, 550, 555, 560, 565, 570, 575, 580, 590, 610 and 630 mμ. Since the obtainment of one saturation threshold for these 19 hues required about six hours, two experimental sessions of three hours each were arranged. These sessions were alternated with luminosity measurements so that a typical routine was: Day 1: luminosity 1; Day 2: saturation 1—first half; Day 3: saturation 1—second half; Day 4: luminosity 2; etc. The final values are averages of four days' determinations at each spectral point except for C.S. and J.D. who have only three measurements at each point. In obtaining the saturation thresholds a different pre-determined order of spectral hues was used each day so as to balance out practice and fatigue effects. Half of the *S*s, J.H., J.D., L.P., and A.C., were tested with the spectral hues presented on the right half of the test area, and the other half, W.M., C.S., J.B., and M.R.C., were tested with the spectral hues presented on the left half of the test area.

The procedure used in determining a saturation threshold was as follows: White of 1.25 apparent foot-candles was put into one-half of the test area and was kept constant for all measurements. White was then set into the other half and was matched for brightness against the standard white. This preliminary matching served to remind the *S*s of the exact appearance of the neutral surfaces and was undertaken before measurements at each spectral point were begun. To the experimental white was now added the hue in an intensity sufficient for the *S* to recognize it immediately as colored. The intensity of the hue was then decreased step by step until *S* could say definitely that the two sides matched in hue, i.e., both were white. From this point of equality the hue was increased step by step until *S* could again say definitely that the two sides differed in hue. The procedure was then repeated to complete the series for the one hue. The threshold was taken as the mean value between the lowest proportion of hue always judged different from white and the highest proportion of hue always judged equal to it.

Each change in the intensity of the hue caused a change in the brightness of the mixture of white plus hue. It was necessary, therefore, to change the brightness of the white component of the mixture for each successive setting of the hue until the brightness of the mixture matched that of the standard white exactly. Only then could the *S*'s judgment of color equality or inequality be accepted. This insistence on an exact brightness match may seem trivial, but it is actually of the utmost importance. To the normal person the sensation of hue is such a qualitatively distinct one that he has little difficulty in deciding whether two samples which differ in brightness are alike in hue, even though the brightness difference may be relatively large.

This is apparently not the case with the color blind. A mixture which might be called unequivocally colored by such a *S*, would sometimes match the standard white completely after a minor adjustment in the brightness.[6]

Observers

All the color blind *S*s were college students who were paid by the hour for their services. Attempts were made to secure *S*s with varying degrees of color blindness. Descriptions of the *S*s are presented below in some detail in order to justify the ranking of these men according to the degree of their color blindness. The descriptions are arranged in the order of increasing color blindness for the deutero- and proto-groups separately.

Subject J.B., 20 years old, had no major optical defects. Uncorrected vision in the left eye[7] was 20/38. According to J.B.'s statement, he had no idea of his color deficiency until the time of his examination at the Department of University Health. He remembered no instances of difficulty in the matching or naming of colors. His responses to the Pseudo-Isochromatic Plates (2) are shown in Table I, and to the Ishihara test (13) in Table II. The most outstanding item of his test results is that he read plates 18–21 more easily than plates 14–17 on the Ishihara. The latter four plates are read by the normal only with extreme difficulty. No outstanding color confusions were noted during luminosity and saturation measurements. It was concluded that J.B. was very slightly deuteranomalous.

Subject C.S., 24 years old, had no major optical defects. Uncorrected vision in each eye was 20/20. C.S. first noticed his defect a few years ago when he read some incorrect responses on the Ishihara test. He insisted that he had no difficulty in naming or matching colors in everyday life. On the Ishihara and Pseudo-Isochromatic Plates, C.S. tested completely deuteranopic when he viewed the charts at a distance of three feet. At a distance of 10 feet his errors were reduced considerably (*cf.* Tables I and II).[8] During luminosity and saturation measurements errors in color naming were frequently noted but they were not outstanding. A careful search for a neutral point yielded negative results; saturated monochromatic bands from 490 mμ to 510 mμ at 1 mμ intervals were always called noticeably colored as compared with the gray.

Subject J.D., 18 years old, was slightly myopic (uncorrected vision was 20/30 in the right eye). J.D. had known of his color defect for a long time. He had always disagreed with people on certain color names, and had always had difficulty in matching some colors. In the chemistry laboratory he confused sodium yellow with strontium green in the flame tests for these elements. In order to achieve consistent results with the flame test he had to burn the unknown next to a known sample, in which case the difference or similarity could be noted. A red signal light on the control panel of the apparatus was called 'green,' 'red,' or 'possibly yellow.' The point of lowest saturation was not determined for J.D. These determinations were ordinarily made at a special session because the use of very saturated mixtures in the region of 500 mμ required the use of a darker comparison gray which was calibrated separately for the individual. J.D. was not available to complete this session.

On the basis of the color confusions which C.S. and J.D. report from ordinary life situations, it might appear that the latter was more color blind. When the two were presented with isolated color stimuli in the darkened room, however, their confusions were quite similar. It was concluded, therefore, that these two men had about equal amounts of defect, but that C.S., an advanced medical student, had learned to compensate for his defect more adequately than had the younger J.D.

---

[6] *S*s who could not believe they were making this error were usually convinced by the following simple demonstration: Two grays, differing slightly in brightness, were placed in the test areas. Almost invariably, the true dichromats and two of the anomalous observers called the darker gray colored. Increasing the brightness of the darker gray until it was slightly brighter than the standard made the color appear to change sides. A normal *S* could always recognize the grays.

[7] Throughout these descriptions, reference is made always to the eye used in the experiment.

[8] Miles and Craig (16) have shown that a few color-blind observers are able to read more of the Ishihara charts correctly if they view them at a distance of about 10 feet. This finding is interpreted as meaning that the foveal regions in the retinas of such individuals are relatively more color normal than the para-foveal areas. Two of the *S*s in this experiment, C.S. and J.D., were better when tested at a distance of six to 10 feet, while the other four were not.

XUM

TABLE I

RESPONSES MADE BY SIX COLOR DEFECTIVE INDIVIDUALS TO THE PSEUDO-ISOCHROMATIC PLATES FOR TESTING COLOR PERCEPTION
(All responses are recorded. Responses in parentheses were made at a distance of 6 to 10 feet from the chart.)

Plate Number	Deuteranomalous			Deuteranopic	Protanomalous	Protanopic
	J.B.	C.S.	J.D.	L.P.	J.H.	W.M.
1	+	+ (+)	+ (+)	+	+	+
2	+	+ (+)	+ (+)	+	+	+
3	++	−− (−−)	++, +− (−−)	−−	−−	−−
4	++	−− (−−)	−− (−+, ++, −+)	−−	−−	−−, ++, −+
5	+−, ++	−− (−−)	−− (+−, ++)	−−	++	++, +−
6	++	−− (−−)	−− (−−, −−)	−−	−−	−−
7	++	−− (−−)	+− (−−, +−)	+−, −−	++	++, +−
8	++	++ (++)	++ (++)	++	++	++
9	+	+ (+)	+ (+)	+	+	+, −
10	+?	+ (+)	− (+)	−	+	−, +
11	+	− (+)	− (+)	−	+	−
12	+	+ (+)	− (−, +)	−	+	−
13	+	+ (−)	+ (−, −, +)	+	+	+
14	++	−− (−−)	−− (−+, ++, +−)	−−	−−	−−
15	+	+ (−, +)	+ (+)	+	+	−
16	+	− (−)	−, + (−, −)	−, +	+	+
17	++	++ (+−)	++, +− (++)	++	++	−+
18	−+, ++	−+ (−+, −+)	++ (−+, ++)	++, −+	++	−+
19	++	−+, −+, −+ (++)	−−, −− (−−)	−−−	++, −−?	−−−, −−−
20	+	− (−, +, −, −)	− (+, −)	+	+, −	+
21	+	− (−, +)	− (−)	−	−, +	−
22	++	++ (++)	++ (++)	++	++, +−, −−	−−
% Digits read correctly	95	45	52	44	63	43

TABLE II

RESPONSES MADE BY SIX COLOR DEFECTIVE INDIVIDUALS TO THE ISHIHARA TESTS FOR COLOR-BLINDNESS
(All responses are recorded. Responses in parentheses were made at a distance of 6 to 10 feet from the chart.)

Plate Number	Deuteranomalous			Deuteranopic	Protanomalous	Protanopic
	J.B.	C.S.	J.D.	L.P.	J.H.	W.M.
1	++	++ (++)	++ (++)	++	++	++
2	−, +	− (+)	− (+)	−	−	−
3	+	− (+)	− (+)	−	−	−
4	+−, −−, ++	−− (++)	−− (++)	−−	−−	+−, −−
5	++	+− (++)	+−, −− (+−, ++)	−−, −−	+−	−−, +−
6	−, +	− (+)	− (−, −, −)	−	−	−
7	−, +	− (−)	−, − (−, +, −)	−	−	−
8	++	+− (++)	+− (+−, −+)	+−	+−	+−
9	−−, +−, ++	−− (++)	−− (−−, +−)	−−	−−	−−
10	+	− (+)	− (+)	−	−	−
11	+	− (+)	− (+)	−	−	−
12	++	−− (−+)	−− (−+, ++)	−−	−−	−−
13	++	−− (+−)	−− (++)	−−	−−	−−
14	−, +, −	− (−)	− (−)	−	−	−
15	+	− (−)	− (−)	−	−	−
16	++	−− (−−)	−− (−−)	−−	−−	−−
17	++, +−	−− (−−)	−− (−+)	−−	−−	−−
18	−	− (+)	− (+)	−	−	−
19	−	− (+)	− (+, −)	−	−	−
20	−−	−− (++)	−− (+−, −−, −−)	−−	−−	−−
21	−−, −−	−− (++)	−−, −− (−+, −−, −−)	−−, −−	−−	−−, −−
22	++	+− (+−)	+− (+−, +−)	+−	++	−+, −−
23	++	+− (+−)	+− (+−, ++)	+−	++	−+, −−
24	−+	+− (+−)	+−, −− (+−, −−, ++)	+−	−+	−−, −+
25	++	+− (+−)	+−, −− (−−, +−, ++)	+−	−+	−+
% Digits read correctly	63	44	36	16	25	17

Subject L.P., 22 years old, had uncorrected vision of 20/15 in the left eye. L.P. had suspected his defect for a long time. He readily confused colors seen at a distance, and had difficulty in finding ripe apples on a tree or in recognizing a poinsettia on a bush. In certain titration work in the chemistry laboratory he could not tell when a solution changed in color from neutral to green. During saturation and luminosity measurements, errors in color naming were very common. The designation 'yellow' was applied to all desaturated colors from 510 mμ (blue-green) to 610 mμ (orange-red). A mixture of white and 630 mμ (red to the normal) was called 'red,' 'yellow,' and 'green' at different times. A mixture of 630 mμ plus white was once called 'white' while the gray paired with the mixture was called 'blue-green.' Of two neutral grays the darker was always called 'green.' When 500 mμ was paired with a gray of the same brightness the two were thought to match. On the basis of these results L.P. was adjudged to be a true dichromat of the deuteranopic variety.

Of the red deficient *Ss*, J.H., 19 years old, was both astigmatic and nearsighted; uncorrected

TABLE III

RELATIVE LUMINOSITIES OF VARIOUS SPECTRAL HUES FOR TWO NORMAL AND SIX COLOR DEFECTIVE SUBJECTS

(Figures in parentheses were obtained by matching the hues against the less bright of two comparison grays.)

λ	A.C.	M.R.C.	J.B.	C.S.	J.D.	L.P.	J.H.	W.M.
470	(6.7)						(8.1)	(9.4)
480	(8.6)			(7.9)			(10.8)	(12.4)
490	(13.6)	(7.8)	(10.2)	(8.4)	(11.1)	(6.5)	(17.1)	(18.2)
500	(26.3)	(15.4)	(17.9)	(15.2)	(14.3)	(11.1)	(27.1)	(30.3)
	21.9						25.4	29.0
510	(42.2)	(27.0)	(29.1)	(26.7)	(21.6)	(20.3)	(39.7)	(46.6)
	35.6	23.9	25.5	25.8	24.2	22.1	38.1	45.5
520		(38.0)	(39.5)	(41.6)	(36.1)	(32.3)		
	56.3	36.9	43.1	35.4	30.2	29.1	55.8	56.7
530				(44.9)	(31.1)	(39.4)		
	67.4	51.1	59.3	46.0	39.0	39.4	72.2	70.8
540	82.5	64.9	73.6	60.1	49.0	53.5	83.3	88.6
550	91.0	79.1	76.1	70.1	56.8	71.9	94.6	96.5
555	93.8	83.2	89.1	80.4	67.6	73.7	100.0	100.0
560	97.4	88.9	89.7	81.9	69.4	82.0	100.0	100.0
565	99.3	94.1	87.6	91.2	85.1	86.9	95.9	92.4
570	100.0	96.0	96.9	93.1	86.6	96.1	88.1	82.9
575	99.3	98.6	100.0	104.0	97.6	100.0	85.9	77.6
580	98.7	100.0	93.4	100.0	96.2	98.0	76.1	66.9
590								(48.3)
	90.4	96.0	88.6	96.7	97.1	89.6	56.9	50.8
600							(37.9)	(35.0)
	78.6	86.2	75.7	83.0	87.7	82.0	37.4	35.4
610							(22.8)	(20.8)
	65.1	69.6	67.8	64.2	71.2	63.8	25.3	
620	(36.3)		(43.1)			(36.1)	(11.3)	(12.3)
	47.6	46.8	43.9	50.7	54.6	43.5		
630	(27.0)	(31.7)	(31.6)	(32.2)	(39.3)	(26.7)	(6.8)	(8.4)
	28.1	33.8	31.3	33.5	39.7	29.3		
640	(14.5)	(21.6)	(21.4)	(21.6)	(24.5)	(16.8)		
	21.7	23.3	21.7	29.0	26.9	21.9		
650	(9.4)	(12.3)	(11.7)	(15.1)	(17.0)	(9.1)		
660	(7.9)	(7.5)	(8.0)	(10.2)	(13.0)	(6.4)		
Brightness (in app. ft.-c.) of brightest hue	2.32	2.43	2.22	1.99	1.75	2.40	2.50	1.80
Measured at λ	570	580	575	580	580	575	560	555

vision in the right eye was about 20/50. Because of the difficulty of finding good protanomalous observers[9] it was decided to use this *S*. According to his report he never suspected his color defect until the time of his health examination at the university. The only difficulty he had ever noticed in color matching was in the matter of seeing black type on dark red filing cards. During luminosity and saturation measurements, the chief confusions noted were two: (1) a tendency to call the darker of two grays 'red' and (2) a tendency to designate as 'yellow' low saturations of red, yellow, and yellow green. A careful search revealed no true neutral point. The point of lowest saturation occurred at about 487.3 mμ.

Subject W.M., 19 years old, had no major ocular defects; uncorrected vision was 20/20. W.M. had suspected his color defect for many years; he had been painting since childhood and people sometimes disagreed with his color matches. He admitted confusing reds and greens, particularly in low saturations. In driving late at night he was likely to stop before a traffic light which was not working because he could not be sure whether the red signal light was on or not. On the color tests his performance was definitely worse than J.H.'s. During luminosity measurements he was apt to call all hues from 510 mμ to 630 mμ 'yellow.' Frequently, however, he would say that the yellow turned to red as the brightness of the hue was decreased. He often complained about the large number of 'yellows' offered him and inquired once if he were being tested with the whole spectrum or only with blues and yellows. In fact, the only colors which were recorded as having been called 'green' were a mixture of gray plus 590 mμ (orange), a mixture of gray plus 630 mμ (red), and 500 mμ (blue-green). Efforts to discover a true neutral point were indecisive. When a blue-green of about 487 mμ was paired with a gray and W.M. was asked to match the two for brightness just as though he were matching the two grays preliminary to a series of saturation measurements, he would agree that they matched completely at one brightness. As soon as he was informed of the true colors, however, he usually said that he could see a difference if he looked very hard. About half through the experiment, W.M. became involved in academic difficulties, lost sleep rather consistently and began giving erratic results.

Subjects A.C. and M.R.C. served as normal controls. As far as can be determined from a variety of color vision tests, both are color normal and have normal acuity.

As a crude means of quantifying the data obtained on the color tests, the data of Tables I and II may be lumped together and the percentages of correct responses may be calculated for each subject. Thus, of the total number of responses made to the 47 color plates on the two tests, 76 percent of those made by J.B. were correct. The corresponding figures for the other *S*s are: C.S.—45 percent; J.D.—43 percent; L.P.—29 percent; J.H.—44 percent; and W.M.—29 percent. These values together with the descriptive information presented above constitute the criteria of the extent of the color anomaly present in these *S*s.

In order to rule out the possibility that some of the *S*s might have acquired color defects, they were all asked whether they had had any serious ocular, facial or cranial injuries. Results of this questioning were negative. Three of the *S*s, J.D., L.P., and W.M., knew also of at least one blood relative (excluding the father and paternal relatives) who was either color-blind or color-weak. It is safe to assume, therefore, that all of the *S*s were congenitally color defective.

Results

The relative luminosity data (Table III) require little discussion. Since a measure of the brightness of the empirical spectrum was needed in the computation of least perceptible colorimetric purity, the luminosity curves were not corrected for an equal-energy spectrum. The data presented are, however, in agreement with the earlier studies of Abney (**1**), Exner (**4**), Hecht and Shlaer (**11**), and Pitt (**21**). The curves of the protanope W.M. and the protanomalous J.H. reach their maxima at about 555 mμ and 557 mμ as compared with 580 mμ and 575 mμ for the normals M.R.C. and A.C. The

[9] Deuteranopes are roughly two or three times as common as protanopes.

curve for the deuteranope L.P. reaches a maximum at about 575 mμ; for the deuteranomalous J.D. at 582 mμ; for C.S. at 580 mμ and for J.B. at 575 mμ.

As an incidental observation it is worth noting that the ease of making brightness equality judgments seems to be inversely related to the degree of color defect in the individual. Systematic records were not kept as regards this matter, but the normals required from one and one-half to two times as long to run through a complete series of luminosity measurements as did the deuteranope L.P. or protanope W.M. The latter *S*s, too, reached their decisions with very few adjustments, while M.R.C. commonly made two or more adjustments before a satisfactory match was obtained. If this observation is correct, it finds an easy interpretation in the fact that the spectral hues appear generally less saturated, i.e., nearer to white or gray, to the color blind, and hence are more easily matched in brightness with gray.

Fig. 2 is a compliation of normal data on the least perceptible colorimetric purity from the researches of Grether (**9**), Priest and Brickwedde (**22**), Nelson (**19**), Wright and Pitt (**27**), Purdy (**23**) and Martin, Warburton and Morgan (**15**). Although these data were obtained under varying experimental conditions, they all agree in showing a point of low saturation in the yellow and yellow-green region (*ca.* 565–570 mμ) with increasing saturation at both spectral extremes. The normal curves obtained in this investigation (*cf.* Figs. 3 and 4) are comparable with those shown in Fig. 2.

The saturation data obtained in this study are presented in Table IV and in Figs. 3 and 4. Fig. 3 summarizes the saturation curves for the two normal observers, the deuteranomalous J.B., J.D. and C.S. and the deuteranope L.P. Fig. 4 shows the saturation curves for the normal observers, the protanomalous J.H. and protanope W.M.

Two fairly consistent trends may be noticed in these charts. The first is a decrease in the saturation of the spectrum for the color blind and the second is a shift in the relative saturation of various parts of the spectrum. The first result, the decrease in saturation, may be seen in both charts. The normal curves are everywhere higher, i.e., indicative of greater saturation, than comparable curves for the color-blind. The points of contact between the curves of the normal and color-blind are at 470 mμ, and in the yellow and yellow-green region around 565 mμ. Too much reliance, however, must not be placed on comparative figures for 470 mμ. In most cases, measurements on the luminosity curves do not extend below 480 mμ, so that it was necessary to extrapolate these curves in order

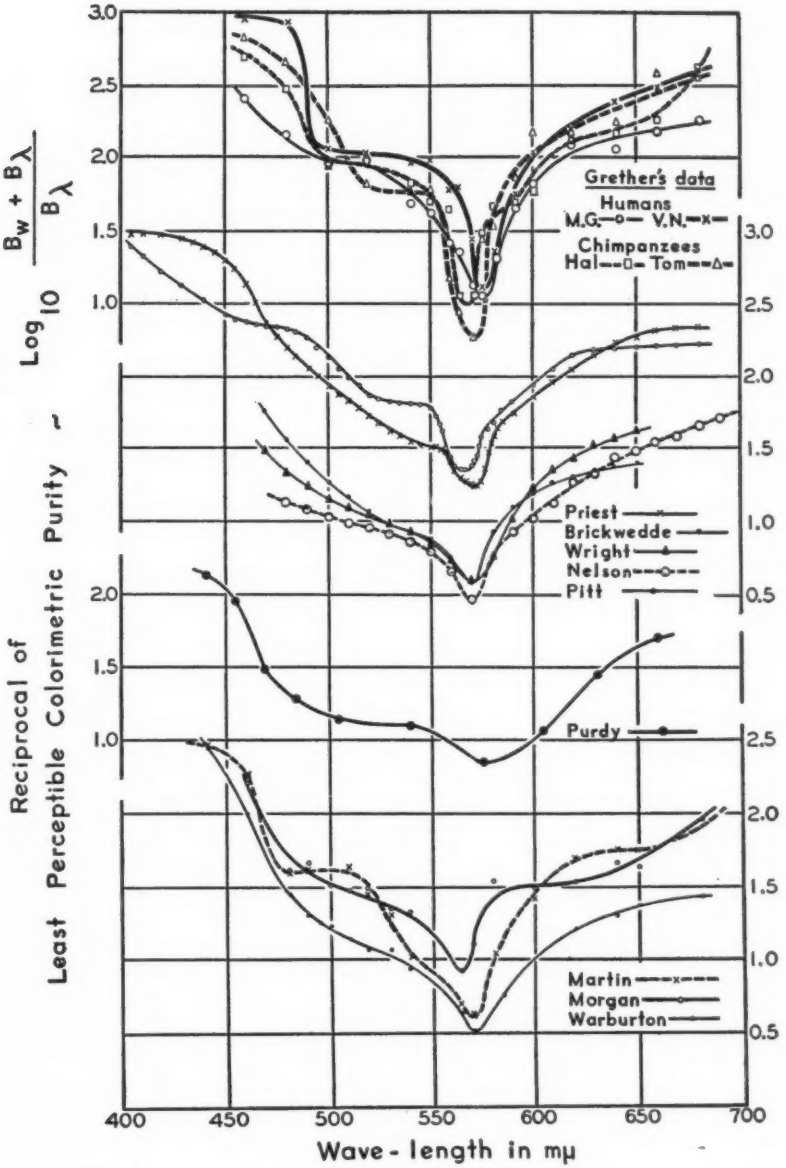

FIG. 2. Curves of the reciprocal of least perceptible colorimetric purity from the data of Grether (9), Priest and Brickwedde (21), Nelson (18), Wright and Pitt (26), Purdy (22), and Martin, Warburton and Morgan (15). The smooth curves drawn through the observed values are those of the writer and may not agree exactly with the originally published curves. (Proceeding from top to bottom, the ordinate scale is read alternately on the left and right sides of the chart for each of the four groups of curves.)

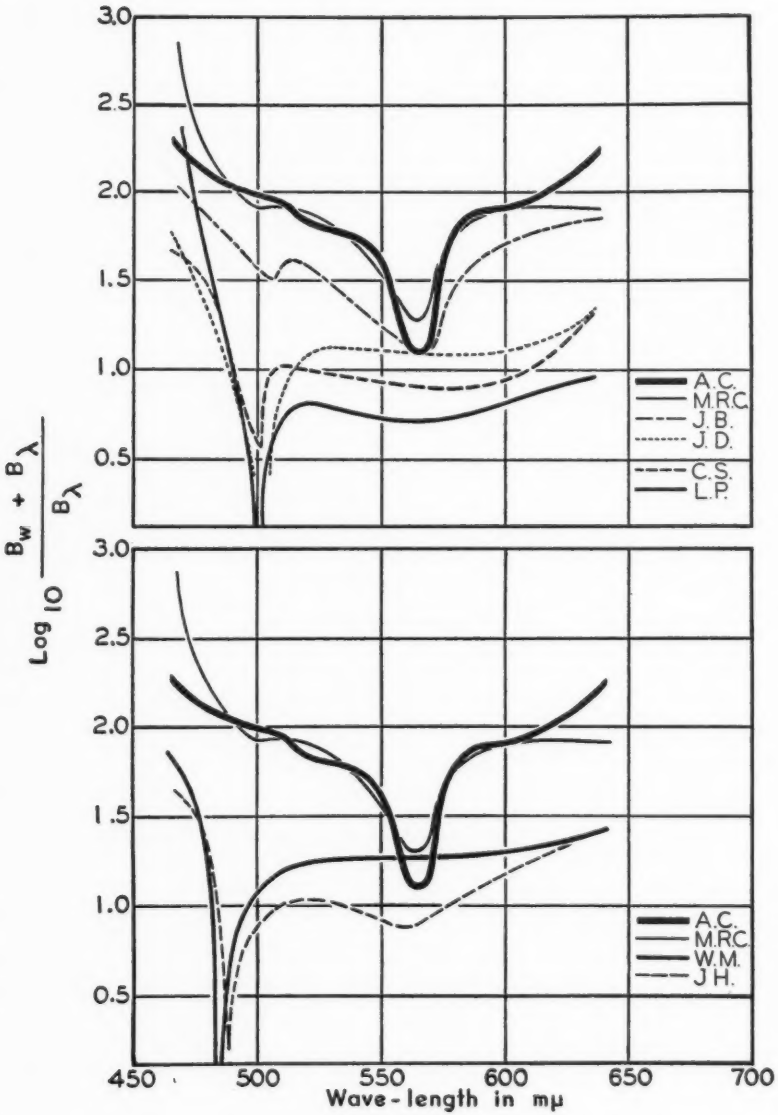

FIG. 3. (Above) Saturation thresholds for two normal, three deuteranomalous and one deuteranopic observer.

FIG. 4. (Below) Saturation thresholds for two normal, one protanomalous and one protanopic observer.

to obtain a measure of the brightness of 470 mμ [10] for use in the formula for least perceptible purity.

Incidental observations which tend to confirm the finding of the decrease in saturation were made during the experimental sessions. The *E* frequently looked at mixtures which the *S*s were willing to call equal to gray. In almost every case, threshold mixtures for C.S., J.P. and J.H. appeared unequivocally colored to his eye. Threshold mixtures for J.D. and W.M. were difficult to judge in the region of 565 mμ but elsewhere in the spectrum their matches ap-

TABLE IV

SATURATION OF VARIOUS SPECTRAL HUES FOR TWO NORMAL AND SIX COLOR DEFECTIVE SUBJECTS

λ	A.C.	M.R.C.	J.B.	C.S.	J.D.	L.P.	J.H.	W.M.
470	2.20	2.74	1.97	1.60	1.66	2.32	1.57	1.76
480	2.09	2.25	1.83	1.46	1.33	1.53	1.32	1.35
490	2.02	2.02	1.69	0.93	0.95	0.95	0.58	0.70
495	2.00	1.98	1.62	0.71	----	0.00	0.79	1.02
500	2.06	1.89	1.63	0.57	----	0.00	0.93	0.92
505	1.96	1.90	1.46	0.94	0.50	0.65	0.87	1.25
510	1.97	1.96	1.63	1.00	1.14	0.63	1.09	1.12
520	1.82	1.88	1.56	0.98	0.91	0.80	0.92	1.32
540	1.75	1.74	1.34	0.93	1.20	0.75	0.98	1.17
550	1.60	1.53	1.20	0.96	1.06	0.75	0.88	1.19
555	1.30	1.44	1.24	0.85	1.25	0.72	0.89	1.25
560	1.22	1.35	1.09	0.91	0.95	0.78	0.84	1.36
565	1.10	1.34	1.12	0.88	1.05	0.70	0.86	1.21
570	1.45	1.51	1.11	0.93	1.02	0.70	0.88	1.33
575	1.54	1.54	1.32	0.85	1.14	0.73	1.01	1.27
580	1.79	1.80	1.49	0.90	1.04	0.76	1.00	1.35
590	1.87	1.84	1.61	0.86	1.08	0.77	1.12	1.25
610	1.95	1.91	1.76	1.00	1.02	0.87	1.18	1.39
630	2.11	1.91	1.82	1.22	1.26	0.94	1.37	1.30
c	----	----	----	+0.06	+0.12	----	----	+0.11

peared noticeably different to the experimenter. Threshold mixtures for J.B. were harder to distinguish from the gray except at the spectral extremes.

The amount of decrease in saturation appears to be related to the degree of color-blindness. The only reversal in the data are the relative saturation thresholds of the protanomalous J.H. and protanope W.M. This may be attributed to either or both of the following: (1) J.H.'s myopia may have lowered his ability to make fine color discriminations. Although he claimed that he was able to make precise determinations under the conditions of this experiment and without his glasses, it is probable that this factor tends to vitiate

[10] The brightness of the empirical spectrum was so low at 470 mμ that luminosity measurements could not be obtained with any consistency. In addition to the low brightness, there was an appreciable contrast effect from the white screen which surrounded the test area.

his results. (2) Different criteria may have been used by these two observers in deciding when a mixture really matched a gray. It is reasonable to expect, of course, that variations in individual criteria might have a substantial effect on results obtained. Priest and Brickwedde (**22**), for example, found about 0.3 log units difference between the 'least purity perceptible with certainty' and the 'greatest imperceptible purity.' Presumably, therefore, mixtures which fell between these limits and were paired with gray, might or might not be called colored, depending on whether the individual's criterion of equality was high or low. In this experiment there was a small range of mixture proportions which these *S*s could not see as colored, but which still did not match the gray completely. They were instructed to judge these doubtful mixtures on the basis of whether or not they thought they could tell which side was colored if the mixture and gray were changed from side to side in a random order. This criterion was at best, however, subjective, and permitted some latitude. The procedure of taking the threshold as the mean value between the lowest judgment of inequality and the highest one of equality would tend, on the other hand, to give measures somewhere near the middle of the range of uncertainty.

Nothing can be said regarding the comparative levels of the saturation curves for the protanopic versus the deuteranopic, since the number of cases is too few.

One important factor which determines the levels of the saturation curves is the brightnesses of the various spectral hues (see the formula for least perceptible colorimetric purity, above). Technical difficulties were encountered, however, in the conversion of the relative luminosity curves into photometric units. The calibration was always undertaken for that hue which was maximally bright for each *S*. Since luminosity measurements were always made by matching against a white of standard brightness, it was possible to calculate in photometric units the brightness of the lightest hue in the spectrum and, from that, the brightnesses of the other spectral hues.

Since white is the sum of the brightnesses of all the spectral hues, the brightnesses of the highest points in a number of luminosity curves should be about the same, as long as the curves have approximately the same form. Those which tend to be relatively narrower than the normal, which is the case with some of the curves for the color blind, should have correspondingly higher maxima. Maxima were computed to be the following: for A.C., 2.32; for M.R.C., 2.43; for J.B., 2.22; for J.D., 1.75; for C.S., 1.99; for L.P., 2.40; for J.H., 2.50; and for W.M., 1.80 apparent foot-candles. The maximum for A.C. was checked directly against readings obtained with the Macbeth Illuminometer. The average reading obtained in this way was

2.30 apparent foot-candles. The use of this instrument is not a validating check since it employs the same heterochromatic brightness matching method as was used in obtaining the luminosity curve. The only reason for checking against the illuminometer is that this instrument uses a photometric field (a central disc surrounded by an annulus of standard brightness) which might make brightness comparisons more consistent than the split field used in the spectral apparatus.

As compared with the maximum spectral brightness obtained for the five observers who range around 2.30, the figures for C.S., J.D. and W.M. are clearly below what might be theoretically expected. It is probable that these deviations represent differences in the *S*'s criteria of what constitutes a heterochromatic brightness match. Since deviations as large as these result in an appreciable change in the final levels of the purity limens, it was assumed that the true brightnesses of the maxima for these three curves was at least 2.32 apparent foot-candles, and saturation curves were computed accordingly. Use of the empirically obtained brightnesses would alter the saturation curves in the direction and in a magnitude indicated by the correction factor 'c' in Table IV. Deviations in the maximum spectral brightness as large as 0.20 apparent foot-candles result in relatively no change in the final level of the purity curve, so that corrections were not applied to the curves of the other five observers.[11]

The second matter of interest in the saturation data is the shift in the relative saturation of various spectral hues. The greatest change in saturation occurs in the blue-green region of the spectrum (*ca.* 500 mμ) and the least in the yellow-green (*ca.* 565 mμ) and, probably, also the extreme blue. If the data are considered in terms of the amounts of the color vision defects, saturation of the blue-green is highest for the normals A.C. and M.R.C., lowest for the dichromats L.P. and W.M., and intermediate for the anomalous observers. It is difficult to estimate how much reliance may be placed on the dip at 505 mμ in J.B.'s curve in view of a similar depression which occurs in the curve of the normal M.R.C. Even assuming that the dip at 505 mμ for J.B. is an experimental error, the points at 500 mμ and 510 mμ are sufficiently different from the

[11] Walsh (26) discusses the problem of subject-variability in criteria with reference to daily variations in heterochromatic brightness matching, but does not touch on the critical problem here. His statement, however, shows the importance of the psychological factors: "not only do different observers disagree markedly, but the same observer becomes inconsistent from day to day. It is a somewhat curious psychological effect that, with a considerable colour difference, a single observer may obtain very consistent readings during the course of a single set of observations, but on another occasion his readings, although again consistent among themselves, are quite different from his previous set. There is apparently an unconscious adoption of a certain criterion of equality which, although remembered throughout a single set of measurements, is forgotten if a considerable period elapse between one set and the next" (pp. 237 ff.).

XUM

normal values to leave little doubt concerning the trend. Although efforts to secure an anomalous observer slightly worse than J.B. but better than C.S. or J.D. were unsuccessful, the tendency seems clear enough.

Nothing final can be said regarding the exact location of the point of low saturation for the proto- versus deutero-observers. Hecht and Shlaer (11), in a summary of 46 neutral points found by three investigators, report that the average of 21 protanopic neutral points is 496.5 mμ; for 25 deuteranopes, 504.3 mμ. The overlap between the neutral points for the two types of dichromats is so great that this value cannot be used as a basis for differentiating them. Points of low saturation reported here correspond to the values reported by Hecht and Shlaer.

It is interesting to note that the point of low saturation which occurs at 500 mμ for the dichromat does not appear to be the result of a shift in the point of low saturation from the yellow-green to the blue-green. The data presented here support the conclusion that the anomalous observers possess two regions of low saturation, one at 565 mμ (corresponding to the normal dip there) and one at 500 mμ (corresponding to the dichromatic neutral point).

The general shapes of the purity limen curves for the two dichromats L.P. and W.M. agree with the empirically obtained saturation curve for Hecht and Shlaer's protanope H.J. and with the theoretically obtained curves for their protanope H.J. and their deuteranope A.W.G. (12). The two sets of data, therefore, are probably expressions of the same basic physiological mechanism. It should be pointed out that the ordinates on the Hecht and Shlaer charts are not comparable with those of the present study because the former are not charts of purity limens. In the text of their article, however, these investigators report determinations of purity limens for two hues, 440 mμ and 650 mμ, and indicate that for their protanope, 440 mμ is about 1/5th and 650 mμ is 1/20th as saturated as they are for the normal eye. The data here are roughly in agreement with their values. 630 mμ was found to be 15 times more saturated for A.C. than for L.P. and about six and one-half times more saturated than for W.M.

Discussion

The interpretation of these findings in the light of modern color theories is extremely difficult because there is at present no theory of color blindness which can consistently integrate the simpler data of color blindness with the data of normal color vision. This is perhaps illustrated most clearly by the difficulty which theorists encounter in

attempting to explain the differences found in the spectral brightness distribution of the normal, protanope and deuteranope.

A second difficulty lies in the fact that there is at present only the very beginning of a theory of saturation for the normal eye. That this dimension of color has been neglected by theorists, even though it was identified long ago by as great a man as Helmholtz, may be due partly to the lack of experimental data and partly to the difficulty of imagining the kind of physiological mechanism that would account for it. The data on trichromatic color mixture matching of the spectrum may be easily explained by assuming three different kinds of cones or photosensitive substances. Brightness is easily conceived as varying according to the number of cones stimulated. The mechanism of saturation, however, is not so easily visualized. The tacit assumption underlying present ideas on this matter seems to be that the three types of cones yield sensations of equal saturation,[12] and that variations in the saturation of the spectral colors are produced by the overlap of desaturating sensations from one or another of these types of cones.

If this hypothesis is correct and if, further, dichromatic vision is a true reduction system from the normal, i.e., one of the color sensitive cones or photosensitive substances is missing, one might predict that blue should be equally saturated with red or with green and that the saturation curve for red should be level at the extreme end of the spectrum above 590 mμ where the sensibility of the blue receptor mechanism presumably ends. Neither of these predictions for dichromatic vision is substantiated by the data reported here.

The alternative explanation of anomalous and dichromatic vision is that one of the color-sensitive elements, e.g., the red, is less completely differentiated from another of the elements, e.g., the green, in the anomalous, and that the two types of cones have identical ranges of spectral sensitivity in the dichromatic eye. Pitt (**21**) has ventured the prediction that if this is the correct explanation for anomalous vision there should be a gradual shift in the point of low saturation from 565 mμ toward the blue-green region. Grether (**9**) (*cf.* also Fig. 2) reported exactly such a shift for two chimpanzees who, on the basis of results on other visual functions (**7**), (**8**), might be thought of as slightly anomalous. Here again, there is no supporting evidence in this study for such a theoretical interpretation of color blindness. As was indicated earlier, the anomalous data exhibit two points of low saturation, one at 565 mμ (corresponding to the point of low saturation for the normal) and one at 500 mμ

[12] This is shown in the time-honored practice of equating areas under the curves obtained from color mixture data. The assumption here is that the three types of cones contribute equally to the sensation of white, i.e., that they have equal chroma-cancelling power.

(corresponding to the neutral point of the dichromat). It should be pointed out that the shift in the chimpanzee point of low saturation may be entirely irrelevant to this discussion inasmuch as the color vision of the infra-human *S* may be different from that of the true anomalous. Evidence for this possibility may be adduced from the fact that chimpanzee hue discrimination curves (**8**) do not resemble those obtained for the anomalous (**21**).

Hecht and Shlaer (**12**) have questionned the use of purity limens as measures of saturation in the color blind. Purity limens for normal *S*s are known to be correlated with other measures of saturation, e.g., the number of discriminable steps in saturation (**14**), (**23**), the intensity required for the spectral hues to reach full saturation (**23**), and the luminosities required for complementary hues to match gray (**10**). Whether these relationships will be substantiated for the color blind is a problem for future research which cannot be answered here.

There is still some question as to whether anomalous color vision is really an incomplete dichromatism (*cf.* Pitt (**21**), for example). The data reported here tend to support an affirmative answer. As Murray (**17**) suggests, however, the pressing need today is for a determination of purity limens on a thousand unselected individuals. Such data, in addition to answering the theoretical question posed above, might be of immensely practical value. If purity limens are decreased in proportion to the degree of color defect, as was found here for only a few *S*s, the color physiologist would have a basis for constructing a really quantitative scale of color blindness (**18**).

The last point of theoretical interest is that the data reported here are a quantitative expression of the common observation that the anomalous report difficulty in distinguishing many colors, especially the poorly saturated ones, from gray. It can be seen from these data that many of the pastels and dark shades, which are distinguishable as color by the normal, fall below the hue sensibility thresholds for the color defective. Over a period of years the latter learn that the normal frequently apply chromatic names to colors which seem (to the anomalous) indistinguishable from gray. It is precisely this circumstance which made it unusually difficult for the color blind *S*s in this experiment to decide whether a gray was colored. As one of the *S*s remarked: "Maybe I call it colored because every time I see that shade of gray it turns out that someone tells me it's a dark shade of some color." None of the *S*s ever called a gray a 'bright' or 'good,' i.e., saturated, color, but it was difficult for some of them, notably J.D., L.P., J.H. and W.M., to identify a gray as gray and not as colored.

Summary

Saturation thresholds were measured at 19 spectral points by finding the proportion of hue which had to be added to white of 5000° K. to make the mixture appear just discriminably colored. Eight Ss, two normal and six with varying degrees of color vision defect, were used in the experiment. The results may be summarized as follows:

1. Spectral saturation for the color blind observers is generally lower than for the normal observers. The extent of this difference appears to be related to the degree of color defect; the curves for the true dichromats deviate most from the normal values, while those for the color anomalous lie between the two.

2. A shift in the relative saturation of various spectral hues is related to the degree of color defect. The greatest change in saturation occurs in the blue-green region of the spectrum and the least in the yellow and yellow-green regions. Blue-green for the normal observer is a highly saturated hue, for the color anomalous it is less saturated, and for the dichromat it is completely desaturated, i.e., it matches white.

Two hypotheses regarding the nature of color blindness are possible with a tri-receptor color theory. The data reported here are inconsistent with both of these hypotheses. The practical value of the findings is that they may provide a basis for the construction of a quantitative scale of color blindness.

(Manuscript received December 1, 1943)

References

1. Abney, W. *Researches in color vision and the trichromatic theory.* London: Longmans, Green and Co., 1913.
2. Anon. *Pseudo-isochromatic plates for testing color perception.* (American edition) New York: E. B. Meyrowitz Surgical Instruments Co., 1940.
3. Chapanis, A. Spectral saturation and its relation to color vision defects. (Unpublished Ph.D. dissertation) Yale Univ., 1942.
4. Exner, F. Helligkeitsbestimmungen im protanopen Farbensystem. *Sitzungsber. K. Akad. Wissensch., Math.-Naturwissensch. Kl.*, Wien, 1921, **130**, 355–361.
5. Geissler, L. R. Experiments on color saturation. *Amer. J. Psychol.*, 1913, **24**, 171–179.
6. Grether, W. F. A new spectral color apparatus for studies of primate color vision. *J. gen. Psychol.*, 1935, **12**, 450–456.
7. Grether, W. F. Chimpanzee color vision. I. Hue discrimination at three spectral points. II. Color mixture proportions. III. Spectral limits. *J. comp. Psychol.*, 1940, **29**, 167–192.
8. Grether, W. F. A comparison of human and chimpanzee spectral hue discrimination curves. *J. exp. Psychol.*, 1940, **26**, 394–403.
9. Grether, W. F. Spectral saturation curves for chimpanzee and man. *J. exp. Psychol.*, 1941, **28**, 419–427.
10. Hecht, S. Vision. II. The nature of the photoreceptor process. *In:* Murchison, C. (Ed.) *Handbook of general experimental psychology.* Worcester: Clark Univ. Press, 1934.
11. Hecht, S., & Shlaer, S. The color vision of dichromats. I. Wavelength discrimination, brightness distribution, and color mixture. *J. gen. Physiol.*, 1936, **20**, 57–82.

12. HECHT, S., & SHLAER, S. The color vision of dichromats. II. Saturation as the basis for wavelength discrimination and color mixture. *J. gen. Physiol.*, 1936, **20**, 83–93.
13. ISHIHARA, S. *Tests for colour-blindness.* (9th ed.) Chicago: C. H. Stoelting Co., 1940.
14. JONES, L. A., & LOWRY, E. M. Retinal sensibility to saturation differences. *J. opt. Soc. Amer.*, 1926, **13**, 25–34.
15. MARTIN, L. C., WARBURTON, F. L., & MORGAN, W. J. Determination of the sensitiveness of the eye to differences in the saturation of colours. *Spec. Rep. Ser. med. Res. Coun., Lond.*, No. 188, 1933.
16. MILES, W. R., & CRAIG, H. Color blindness in dry goods salesmen. *Person. J.*, 1931, **9**, 437–449.
17. MURRAY, E. The use of Munsell papers in tests diagnostic of color weakness, color blindness, and vocational color capacity. *Amer. J. Psychol.*, 1940, **53**, 445–449.
18. MURRAY, E. "Color blindness": current tests and the scientific charting of cases. *Psychol. Bull.*, 1942, **39**, 165–172.
19. NELSON, J. H. The colour-vision characteristics of a trichromat, Part 2. *Proc. phys. Soc., Lond.*, 1937, **49**, 332–337.
20. PARSONS, J. H. *An introduction to the study of colour vision.* (2nd ed.) Cambridge, England: Cambridge Univ. Press, 1924.
21. PITT, F. H. G. Characteristics of dichromatic vision. With an appendix on anomalous trichromatic vision. *Spec. Rep. Ser. med. Res. Coun., Lond.*, No. 200, 1935.
22. PRIEST, I. G., & BRICKWEDDE, F. G. Minimum perceptible colorimetric purity as a function of dominant wave length. *Bur. Stand. J. Res., Wash.*, 1938, **20**, 673–682.
23. PURDY, D. McL. On the saturations and chromatic thresholds of the spectral colours. *Brit. J. Psychol.*, 1930–31, **21**, 283–313.
24. TROLAND, L. T. (Chairman) Report of Committee on Colorimetry for 1920–1921. *J. opt. Soc. Amer.*, 1922, **6**, 527–596.
25. v. KRIES, J., & KÜSTER, F. Ueber angeborene Farbenblindheit. *Arch. Anat. Physiol., Physiol. Abt.*, 1879, **3**, 513–524.
26. WALSH, J. W. T. *Photometry.* London: Constable and Co., 1926.
27. WRIGHT, W. D., & PITT, F. H. G. The saturation-discrimination of two trichromats. *Proc. phys. Soc., Lond.*, 1937, **49**, 329–331.

SOME EFFECTS OF MENTAL SET AND ACTIVE PARTICIPATION IN THE CONDITIONING OF THE AUTOKINETIC PHENOMENON

BY ERNEST A. HAGGARD AND GILBERT J. ROSE

Harvard Psychological Clinic

Although the statement that we usually see what we wish or expect to see is so commonplace that it may be called a truism, this general problem has only recently received attention in the psychological laboratory. Perhaps the first experiment to show the importance of autism [1] in this connection was performed by Murray (**28**), who had five small girls rate photographs of unknown people in terms of their apparent benevolence or maliciousness after pleasurable play activity and after a game of 'murder.' Three of the girls rated the people as being much more malicious just following the game of murder than they did after ordinary play. From related studies, Sanford (**30, 31**) found that the responses of hungry subjects to ambiguous stimuli contained significantly more references to food than those of subjects who were not hungry. This work was later confirmed and extended by Levine, Chein, and Murphy (**25**).

The subject does not have to be aware of the relation between his mental set and his perceptions. To eliminate the factor of awareness, several investigators have used a system of rewards and punishments in order to build up unconscious mental sets which, in turn, modify the subject's judgments. For example, Proshansky and Murphy (**29**) rewarded college students for estimating the length of lines or weights of objects in a given direction. Their subjects showed significant shifts in their judgments in favor of the direction which had been rewarded. In another study from the same laboratory, Schafer and Murphy (**32**) reported that autism can serve to determine the figure-ground relationship in a visual field. Finally, Leavitt (**24**) changed certain attitudes of his subjects from approval to disapproval by applying a slight electric shock just following the expression of the favorable attitude in such a manner that the subjects were not aware of the relevance of the shock.

A different kind of evidence has repeatedly shown that subjects acquire conditioned responses more rapidly when they take an active

[1] Autism, in this sense, may be defined as the tendency of cognitive processes to move in the direction of tension-reduction.

role rather than remaining passive while learning. In fact, several responses were not acquired at all as long as the subjects remained more or less passive. Since this material has been reviewed elsewhere (17), it will suffice to mention that the importance of active participation was demonstrated in connection with the cardiovascular, eyelid, patellar, and pupillary reflexes, the EEG and GSR, and movements of the ear and arm.

In many respects, the present investigation is most closely related to Ellson's (10, 11) work, in which subjects were conditioned to 'hear' a tone at the presentation of a light. The autokinetic phenomenon [2] was chosen for the present study, however, to determine (*a*) whether perceptual conditioning might be demonstrated in human subjects in connection with visual phenomena, and (*b*) because of the implications involved for certain concepts of brain-dynamics. Primary attention was paid to the subjects' mental set and whether they took an active or a passive role during the experiment.

The Experiment

Subjects

Sixteen college men served as *S*s. Of these, only one had received instruction in psychology (introductory course), and all remained unaware of the purpose and method of the experiment.

Apparatus

The apparatus consisted of a 4-watt bulb connected to a throw switch. The bulb was placed in a small tin can, one side of which was pierced with a pin-point hole. The shelf on which the light was placed was marked off in ¼-inch units, so that before the experiment began, the *S* would think that the light actually moved, and during the experiment would be more able to estimate the magnitude of the movements. The *S* sat 10 feet away from the light in a blacked-out room. The light appeared for 7½ sec. during each trial, and the trials came at about 30-sec. intervals.

Experimental Conditions

Active Participation.

The 'Active' Group.—The eight active *S*s reported (verbally) after each trial whether they saw the light move, and if so, how far to the left or right. In addition, each *S* was given a pad of paper interleafed with sheets of carbon paper on which he drew an arrow the same length and in the same direction as the perceived movement. If no movement was seen, the *S* drew a small circle in the center of the page. Finally, the *S* was asked to make his arrows penetrate as many sheets of carbon paper as possible. This was done to get an approximate measure of the degree of his overt muscular activity.

The 'Passive' Group.—The eight *S*s in this group sat passively during all the trials, and were only required to report after each trial whether the light moved, and if so in which direction. No motor reinforcement was involved.

Mental Set or Expectancy.

The 'Most' Group.—Four of the Active and four of the Passive *S*s were told that although the light would not move during every trial, it would move during *most* of the trials.

[2] The autokinetic phenomenon may be described as the apparent movement of a stationary pin-point light in an otherwise totally dark visual field. For a history of this phenomenon, see references (1) and (16).

The 'Some' Group.—The remaining four Active and four Passive *S*s were told that the light would move during only *some* (i.e., only a few) of the trials.

Rewards and Punishments.

In order to prevent the *S*s from finding out that they were being rewarded for 'seeing the light move to the left' and punished for 'seeing it move to the right' they were told that only part of the trials would count.[3] That is, the experimenter used a predetermined random order of rewards and punishments so that only half of the left and half of the right responses were counted (e.g., **20**). On the other trials the *S* was told, "That trial did not count." When no movement was reported the *S*s were also rewarded and punished in the same random order.

After each rewarded left response, the experimenter said, 'Correct,' and also told the *S* that he would be given five cents; after each punished right response, the experimenter said, 'Wrong,' and told the *S* that he would have to pay five cents. At the close of each session, the *S* was either paid or required to forfeit the appropriate amount, depending on whether he had reported more left or right movements. *The same system of rewards and punishments was used for all Ss during the conditioning periods.* (None of the *S*s became aware by the end of the experiment that the light had not moved at all, or that they were rewarded for 'seeing' it move to the left or punished for 'seeing' it move to the right.)

Procedure

Instructions.—Because of the variations in experimental procedure, there were four forms of instructions. At the beginning of the first session, a few comments were made about the importance of developing tests for the perception of slight movements (as in airplane spotting) in order to increase motivation and keep the *S*s unaware of the purpose of the experiment. Thereupon the *S* was handed the appropriate sheet on instructions. For the Active-Most group, for example, they were as follows:

> "During this test, you will be seated in a dark room. But before we can start it will take several minutes for your eyes to become completely used to the darkness. Before each trial, I will say 'ready' and a few seconds later you will see a point of light in front of you. It will stay on about eight seconds and may move to the right or left or not at all. After the light is turned off, tell me if it moved, and whether to the right or left. Ignore any upward or downward movements. On the trials when it does move, estimate as accurately as you can the direction and distance of the movement and draw this distance on the pad in front of you. *The light will move during MOST of the trials.* But I cannot tell you ahead of time when it will or will not move. Be alert so that you are not caught off guard. In answering say, for example, 'left, 1½ inches' or 'no movement' or 'right, 6 inches,' etc.
>
> "When the light goes off *draw an arrow* pointing in the direction you saw the light move. Make the length of the arrow exactly the same distance the light moved. If it didn't move, draw a small circle in the center of the page. Please *bear down hard enough* so that the impression of your lines will carry through at least five carbon sheets.
>
> "There will be 28 trials during each session. About half of the trials will not count. After each trial I will tell you if your report was correct or wrong or if it didn't count.
>
> "For every correct perception you will receive five cents, but for every wrong one you will have to forfeit five cents. If you are careful you should make more correct than incorrect perceptions by the end of the experiment. But this test is not so simple as it seems, so be accurate in observing and reporting the direction and distance you see the light move."

[3] In a subsequent experiment (**18**), *S*s were conditioned to perceive movement to the right rather than to the left by the same system of rewards and punishments. This was done to check the possibility that the light might 'naturally' move in one direction rather than the other, depending on some central state of affairs. In this later study, a relationship between 'eyedness' and ease of conditioning was found.

Conditioning in this paper is used in the sense of 'conditioned response' rather than 'conditioned reflex,' so that the meaning is not limited, say, to a motor reflex. Furthermore, the 'response' itself was not measured in this study, but rather, the assumption was made that a correspondence existed between the *S*'s visual perception and his report of that perception. Finally, it was assumed that some molar cortical process (such as the level or pattern of excitation) was conditioned during the experiment. See the Discussion, and especially the references to the work of Adrian and Yamagiwa (**2**), Lashley (**23**), and Jasper and Shagass (**21**) and Shagass (**34**).

Sessions 1–5 were run off in the manner described above. At the end of trial 28 of Session 5, however, each *S* was asked to go through 10 extra trials. During these, the *S* reported the direction and distance of the movements, but there were no rewards or punishments. Instead, the *S* was asked to estimate (along a 1–5 scale) the degree of his *confidence or certainty* that each perception was correct.

Session 6 again consisted of 28 trials. At the beginning of this session, each *S* was told:

"In this final session, two conditions will be changed:

a. The movement in either direction will often be very much *greater* than ever before, and

b. The movement will occur *many more times to the right* than it has before.

There will be no rewards or punishments during this session."

Experimental Variables

I. *Frequency of Movement* was measured by counting the number of times the light was reported to have moved—either to the left or right.

II. *Magnitude of Movement* was measured by recording the *S*'s estimates of how far the light moved in either direction.

III. *Direction of Movement* was measured by counting the number of times the light moved to the left or to the right. The 'index of conditioning' was obtained by noting the increase in the proportion of movements seen to the left as the sessions progressed.

IV. *Degree of Confidence* was measured by averaging the *S*s' reported confidence or certainty for the perceived movements to the left, movements to the right, or no movements during the 10 extra trials following Session 5.

V. *Stability of the CRs* was measured by noting the discrepancy between the pattern of perceptions reported during Sessions 5 and 6. (See Instructions, Session 6.)

VI. *Degree of Motor Reinforcement in the Active Group* was measured by counting the average number of sheets bearing the carbon impression of the arrows drawn by the *S*.

Results

I. *Frequency of Movement.*

*S*s in the Active group consistently saw the light move more frequently than did the Passive *S*s. The difference between these groups over the first five sessions lay beyond the .001 level of significance ($F = 27.22$).[4] The progressive shift in this measure between Sessions 1 and 5, however, was negligible, for the Active *S*s perceived movement 81 percent of the time during Session 1 and 83 percent of the time during Session 5, and the Passive *S*s saw movement 67 percent of the time during Session 1 and 68 percent of the time during Session 5.

The effect of mental set or expectancy was not so great in producing movement as active participation, since the difference between the average scores of the Most and Some groups (Sessions 1 to 5) lay at about the .10 level of significance. On the other hand, the change in the amount of movement seen between Sessions 1 and 5 is of greater interest than the over-all averages, since the Most group saw the light move in 71 percent of the trials during Session I and in 81 percent during Session 5, while the Some group dropped from 76 percent to 69

[4] Analysis of variance with 1 and 12 d.f. In order to use this technique a correction was made for percentage scores as follows: $X' = \sqrt{X + .50}$, where X' is the corrected score and X is the obtained percentage.

TABLE I

TABLE OF MEASURES FOR THE FOUR SUB-GROUPS

Measures	Sessions	Experimental Treatments			
		Active—Most	Active—Some	Passive—Most	Passive—Some
I. *a.* Frequency of movement (either left or right)	1 to 5	85%	82%	71%	63%
II. *a.* Percent of times seen to left more than right	3 to 5	68.3%	58%	62%	45%
b. Percent of *Ss* seeing movement left more than right	3 to 5	100%	75%	67%	46%
III. *a.* Average magnitude, left	1 to 5	2.63 in.	1.45 in.	1.15 in.	2.02 in.
b. Average magnitude, right	1 to 5	2.19 in.	1.42 in.	1.04 in.	1.77 in.
IV. *a.* Average confidence in movement to left	5b	4.44	3.53	3.78	2.31
b. Average confidence in no movement	5b	4.25	4.25	1.75	2.86
c. Average confidence in movement to right	5b	4.52	3.36	3.33	3.33
V. *a.* Increase in magnitude of movements	5 to 6	1.11 times	1.54 times	2.66 times	3.20 times
b. Increase in frequency of movements	5 to 6	1.07 times	1.02 times	1.06 times	1.24 times

percent during this interval. (See also Table I for a description of the trends for the various sub-groups.)

II. *Direction of Movement.*

Of the movements perceived during Session 1, the Active *Ss* saw the light move to the left 53 percent of the time, although during Session 5 they reported movement to the left 63.5 percent of the trials. The opposite trend occurred in the Passive group, where there was a drop in movements perceived to the left from 55 percent to 51 percent between the first and fifth sessions. The significance of the relative difference between these groups lay at the .04 level, with an F value of 5.73.

The *Ss* who were instructed that the light would move during most of the trials (regardless of direction) not only saw the light move more frequently, but also saw it move progressively more to the left than did the *Ss* in the Some group. More specifically, the Most group saw movement to the left 55 percent of the trials during Session 1 and 63

percent of the trials during Session 5; the Some group on the other hand, saw it move 53 percent of the time to the left during the first session and 51 percent of the time during Session 5. The significance of the difference between these trends ($F = 6.10$) lies at the .03 level.

It will be recalled that an estimate of the degree of conditioning was obtained by determining the increase in the proportion of movements seen to the left as the sessions progressed from the first to the fifth. Thus, we may say that both the factors of active participation and mental set played an important role in the conditioning of the autokinetic phenomenon in spite of the fact that *all* Ss were rewarded for 'seeing' the light move to the left and punished for 'seeing' it move to the right during the first five sessions. (See also Table I for a description of the trends for the various sub-groups.)

III. *Magnitude of Movement.*

All groups tended to see the light move slightly farther to the left even though only the Active and Most groups saw it move significantly more often in this direction. When the average magnitudes for both left and right for the four groups (Sessions 1 to 5) are considered, we find that the average magnitude for the Active group was 1.92 in., for the Most group 1.75 in., for the Some group 1.67 in., and for the Passive group 1.49 in. This order of groups is the same as that for the frequency of movement and degree of conditioning.

Furthermore, it is interesting to note the effects of rewards and punishments on the magnitude of movements. The record of each *S* was examined to see how often the magnitude in the left or right direction increased whenever the previous movement in that same direction was either rewarded or punished. During Session 1, the *S*s reported that the light moved farther (in the same direction) 35 percent of the trials following reward and 48 percent of the trials following punishment. During Session 5, the magnitude increased to 54 percent of the time following reward and 70 percent of the time following punishment. These data suggest that in this experiment, punishment was the more effective motivating agent, and that the effectiveness of both reward and punishment increased as the sessions progressed. (See also Table I for a description of the trends for the various sub-groups.)

IV. *Degree of Confidence.*

After the first 28 trials of Session 5, the rewards and punishments were suspended. Instead, 10 additional trials were given and each *S* rated himself on his confidence (along a 1–5 scale) in his reported perception. Two general trends appeared. First, all *S*s tended to be

more confident in judgments to the left (3.73) than to the right (3.59), and least confident of no movement (3.03). Second, the groups arranged themselves in terms of confidence in the following order: Active (4.03), Most (3.40), Some (3.33), and finally Passive (3.04). While the difference between the Some and Most groups was negligible ($t = .75$), the difference between the Active and Passive groups ($t = 3.86$ with 15 d.f.) fell beyond the .01 level of significance. (See also Table I for a description of the trends for the various sub-groups.)

V. *Stability of the Conditioned Responses.*

At the beginning of Session 6, each *S* was informed that regardless of the direction that the light moved, it would move *much farther, and many more times to the right* than it had previously. This was done to obtain a measure of the stability of the *S*s' tendency to perceive movement in the direction which had been reinforced.

While these instructions were not particularly effective in altering the frequency or direction that the light seemed to move, there was a marked change in the size of the movements. For example, the movements seen to the left increased from 1.54 in. (Session 5) to 2.35 in. (Session 6), and those seen to the right increased from 1.28 in. (Session 5) to 2.62 in. (Session 6). For the various groups, we find that during Session 6, the Active *S*s reported an average increment in movement of 1.2 times, the Most *S*s one of 1.4 times, the Some *S*s one of 1.6 times, and the Passive *S*s one of 2.9 times as great as that during Session 5. These indicate that the factors of actvie participation and mental set made for stable CRs. We furthermore find that five Active, six Most, seven Some, and all eight Passive *S*s displayed an increase in the magnitude of movements during Session 6. The probability that such a pattern would be obtained if the factor of suggestion were *not* of importance falls at the .74, .29, .07, and less than .01 levels respectively for the four groups.[5] (See also Table I for a description of the trends for the various sub-groups.)

VI. *Degree of Motor Reinforcement in the Active Group.*

It will be recalled that the Active group consisted of four Most and four Some *S*s, and also that the measure of active participation was obtained by counting the number of sheets which bore the carbon impression of the *S*s' arrows. Furthermore, it has been repeatedly noted that the factors of active participation and mental set summated in their effect to determine, for example, the degree and stability of conditioning, and the magnitude and frequency of movement. Would differences in mental set also influence overt muscular activity?

[5] The binomial distribution was used to obtain these *P*-values $[(\frac{1}{2} + \frac{1}{2})^8]$, with the tails of the distribution added together since the direction of the results was not predicted.

When a comparison was made between the recorded pressure of the *Ss* in the Most and Some sub-divisions of the Active group, it was found that the former *Ss* consistently bore down harder [6] on their pads (av. of 7.88 sheets) than did the *Ss* in the Some group, who marked an average of 6.96 sheets. The difference of approximately one sheet indicates a substantial difference of pressure, since the force required to mark the sheets increased progressively with the number of carbons. In any case, the point of interest is that the influence of the two factors again worked together to modify the behavior of the *Ss* who took part in this study.

Discussion

The first question to arise in considering the results of this experiment has to do with the physiological basis of the autokinetic phenomenon. To begin with, the work of Guilford and Dallenbach (**16**) has shown that this phenomenon does not result from movements of the eye, hence cannot be attributed to a change of retinal stimulation. These authors, rather, referred to Ferree's papers (**12, 13**) on the streaming phenomenon as a possible explanation. Ferree described the streaming phenomenon as slowly moving swirls in the visual field which sometimes pass across an after image, and, if the streams are sufficiently strong, may temporarily obliterate it. Guilford and Dallenbach argued that when the streams occur in the vicinity of the point of light, they produce apparent movement of that point much as floating clouds seem to cause the moon to move. The apparent movement of the figure (point of light or moon) is in a direction opposite to that of the ground (stream or clouds). As a confirmation of this assumption, Guilford (**15**, p. 581 f.) reported the occurrence of such streams in connection with the autokinetic phenomenon. One of the present authors (H) also noted that the light seemed to move in the path of the stream, so that the direction which the light would take could be predicted.

If the streaming phenomenon does produce the autokinetic phenomenon, is the 'streaming' grounded in a retinal or in a cortical process? Ferree (**12**, p. 116) attributed it to a "streaming over the retina of some material which is capable of directly affecting the processes that condition visual sensations." There is, however, no conclusive evidence which requires that this state of affairs must be localized in the retina. Ferree (**12**, p. 120) cited evidence to the effect that the streaming is *not anterior* to the retina, but this in no way precludes the possibility that it might be posterior. There are, in fact, at least four lines of evidence which indicate that the streaming effect

[6] The *P*-value obtained by the binomial distribution fell beyond the .001 level.

might occur in the cortical rather than in the retinal field. The first two of these show that differential patterns of excitation and/or inhibition may pass from one area of the cortex to another. (*a*) Lashley (**23**), in discussing the migraine scotoma, pointed out that the disturbance passed across the visual field from the macula to the periphery, that it tended to follow one of several radii, and that "the scotoma are symmetric for the two eyes and so are almost certainly the result of a cortical disturbance" (p. 331).[7] In discussing these findings, Lashley concluded that the evidence provided "indications of dynamic organization of the visual field such that . . . some anteroposterior polarization of the striate cortex is indicated (p. 336)." Again, (*b*) Adrian and Yamagiwa (**2**) demonstrated that the focus of the alpha rhythm is not fixed, but may move over an area of several square centimeters.[8] The two remaining reasons for postulating a cortical locus are, (*c*) that several experimenters (e.g., **1**, **5**, **6**, **7**) have reported that the direction, duration, and form of the apparent movement of the autokinetic phenomenon may be voluntarily determined by the observer, and (*d*) that in the present experiment, certain *S*s were conditioned to perceive movement to the left more than to the right. From the available literature, it would seem very unlikely indeed that both voluntary control and conditioning of visual perceptions could be mediated by the retinal centers.

To assume a cortical locus for the autokinetic phenomenon, however, is in effect saying that certain molar patterns of cortical excitation were clearly modified by the conditions involved in the present experiment. In briefly reviewing the conditions and findings of this study, it will be recalled (*a*) that the *S*s in the Active and Most groups saw the light move farther and more frequently, were more certain that their perceptions were correct, and were more effectively and stably conditioned to perceive movement in the left or reinforced direction, than were the *S*s in the Passive and Some groups, and (*b*) that in spite of the differences between these experimental groups, *all S*s were equally rewarded for perceiving movement to the left and punished for perceiving movement to the right. In more general terms, it was found that the factors of active participation and mental set were of major importance in the conditioning of the autokinetic

[7] These characteristics apply equally well to the autokinetic phenomenon (Cf. Guilford and Dallenbach, **16**). The marked difference lies in the fact that the rate of travel for the migraine scotoma as reported by Lashley is only about three mm. per min. across the striate area (i.e., it takes 15–20 min. to cover the distance between the macula and the periphery of the visual field). In the autokinetic phenomenon, the light may seem to move quite rapidly at times, but no definite statements can be made here about the isomorphic relations between the various physiological and psychological events.

[8] In connection with the alpha rhythm, Lashley pointed out that frequently just preceding the scotoma there were intense angular designs ('fortification figures') which scintillate at a rate of about ten times per second.

phenomenon, and that while the same system of rewards and punishments was administered to all *S*s, not all *S*s were conditioned.[9]

The finding that the system of rewards and punishments was not sufficient by itself to effect conditioning of the autokinetic phenomenon raises the question of the universality of 'reward' as *the* reinforcing agent in learning situations. As a matter of fact, a large body of evidence has accumulated which indicates that other factors—such as mental set and active participation—may facilitate or inhibit the learning of new responses. But aside from these data, many authors hold that the necessary condition for learning is either that the *S* must be given some form of gratification, or that he must experience a reduction of some form of undesirable inner tension. Both of these conditions are commonly called 'reward.' To summarize the position of these writers, it seems to be implicit in their thinking that:

To obtain CRs, the proper response-pattern must be reinforced.
One method of reinforcement, 'reward,' is used successfully in the establishment of CRs.
Therefore, 'reward' is essential if CRs are to be established.

In a previous article (**17**), several lines of evidence were reviewed which point to the importance of the *S*'s mental set and active participation in a learning situation. And although the present experiment demonstrates the importance of both of these factors in the conditioning of the autokinetic phenomenon, it is not feasible to discuss the role of mental set in detail here.[10] To do this adequately, it would be necessary to consider the origin and nature of self-induced sets, or in other words, such topics as 'the psychology of the Self' and 'the psychology of Will.'

With regard to the problem of active participation, however, a large variety of experiments clearly demonstrate that this factor may be of primary importance in the acquisition of new responses. This is often true even when the superimposed or reinforcing activity seems to be entirely unrelated to the response to be acquired or the performance to be learned. For example, Schlosberg (**33**) found that when his *S*s clenched their fists (or even said "ah"), the conditioning of the patellar reflex was facilitated. Moreover, he found that even though the *S*s who did not make such a response received up to four times as many learning trials, their average conditioning scores were less than half as large as those of the *S*s who did make a voluntary response to the conditioned stimulus. Miller and Cole (**27**) similarly

[9] A subsequent study (**18**) has shown that active participation without reward is more effective than reward without active participation in the conditioning of the autokinetic phenomenon.

[10] If mental set is thought of as a form of implicit (yet patterned and directed) activity, the phenomenon may be considered as a form of active participation.

reported that the eyelid response was more rapidly and stably conditioned when their *S*s made a voluntary hand movement at the presentation of a CS. But this phenomenon is not restricted to the more simple reflex patterns. In the learning of nonsense syllables, for example, Bills (**4**) demonstrated the facilitative influence of muscular tension, and Stroud (**36**) reported the same finding in connection with maze learning.[11]

The experiments in which voluntary control was established over previously non-existent or non-voluntary responses also indicate the importance of the *S*'s assuming an active role in the learning situation. In fact, in the several instances reported in the literature, it was always necessary for the *S* to make a voluntary (and at first overt) response in conjunction with the UCS and the CS. The classical study in this field was done by Bair (**3**), in which *S*s became able to contract the retrahens muscle of the ear voluntarily. Bair reported that before this could be done, however, it was first necessary for the *S*s to raise their eyebrows vigorously or clench their jaws while the muscle was stimulated by an electric shock. Eventually the ear could move 'voluntarily' as a result of self-induced stimuli. Similarly, Hudgins (**19**) reported that voluntary control of the pupillary response was established only after a series of trials during which the *S*s made a voluntary response (squeezing a dynamometer) when the CS (bell) and the UCS (change in illumination) were presented, and Menzies (**26**) found that this same general pattern obtained whenever the vasomotor reflexes were conditioned. As a final example of the acquisition of voluntary control over previously non-voluntary responses, Jasper and Shagass (**21**) reported that the blocking of the alpha rhythm could be conditioned by having the *S* press a switch button as he said "Block" and release the switch as he said "Stop." The alpha rhythm was not conditioned to vocal or sub-vocal stimuli unless this manual response was made.[12]

While the above experiments have been concerned with various reinforcing responses which were not directly related to the response pattern to be learned, there is also clear-cut evidence to show that an increase in the degree of active participation in connection with a given response may facilitate the learning and retention of that response. Dernova-Yarmolenko (**9**), for example, attempted to condition movements of the arm in the case of *S*s who took 'active' and 'passive' roles during the experiment. The active group of *S*s was

[11] Courts (**8**) and others have shown that the 'facilitation effect' is not directly proportional to the degree of 'tension,' but rather that an optimal level of tension exists, at which point learning is most facilitated.

[12] Shagass (**34**) later reported that the alpha rhythm could be conditioned if the *S* clenched his fist instead of pressing the switch. But the presentation of the light without the fist-clench did not result in conditioning.

required to move the forearm along an arc in a special apparatus, while the passive *S*s had their arm guided along this same arc by the *E*. Successful conditioning was reported for the active *S*s in 75 of the 86 experiments, while conditioning was established in only 7 out of 99 experiments with passive *S*s. In the case of more complex functions, the same trend has appeared. For instance, Jenkins (**22**) found that *S*s who thought they were acting as 'experimenters' by reading a list of 20 nonsense syllables to another group of *S*s who were instructed to learn the list, recalled a large proportion of the words. More specifically, the 'experimenters,' who had no idea that *they* would be tested, later recalled an average of 10 syllables. Furthermore, those 'experimenters' who later said that they had made no attempt whatever to learn the list that they were reading recalled an average of 8 syllables, or 40 percent of the total list. This is more than would be expected, insofar as neither 'reward' nor 'a self-induced set to learn' were apparently operant.[13] As a final example, Gates (**14**) found that both immediate and delayed recall of meaningful and non-meaningful material was facilitated when the *S*s spent part of the learning time in active recitation. That is, the *S*s who merely read the material recalled least, and those *S*s who spent more and more time in active recitation (i.e., up to 80 percent) also recalled more and more of the material.[14]

Certain findings of the present experiment and those briefly reviewed above can hardly be accounted for in terms of the gratification of a need or the reduction of some internal tension system. Rather, it seems necessary to postulate a 'Law of Active Participation,' to the effect that *when an individual assumes an active role in a learning situation, (a) he tends to acquire the responses-to-be-learned more rapidly, and (b) these response-patterns tend to be more stably formed, than when he remains passive.*

A possible description of the state of affairs which accompanies active participation may be as follows:

a. The central state involved in the 'decision' to make certain responses is more or less responsible for the initiation of these responses, and indirectly results in

b. an increase in proprioceptive stimulation which accompanies the (preferably voluntary and overt) responses made by the *S* in conjunction with the UCS and CS in the learning situation, which

[13] Shellow (**35**), in an earlier study on incidental learning, made the point that in either intentional or incidental learning, fixation depends on some form of response.

[14] This study by Gates suggests another generalization, namely, that within limits, the degree of learning tends to be proportional to the extent to which the *S* takes an active role in the learning situation. This trend is also demonstrated in the above-mentioned studies by Bair, Courts, Jenkins, and Schlosberg.

c. raises the 'vigilance' of the central state of affairs (or lowers the 'excitation threshold'), which
d. facilitates 'central integration,' which
e. facilitates the acquisition of new responses or the learning of new performances.

Finally, in comparing the Law of Effect with the Law of Active Participation, it appears that whereas the former is concerned with a facilitating state of affairs which *follows* the response-pattern-to-be-learned, the latter is concerned with a facilitating state of affairs which *exists at the time* the given response-pattern is made. On the basis of the material cited above, it appears that since both conditions facilitate the establishment of new response-patterns, both may serve as reinforcing agents in a learning situation.

Summary

The experiment was designed to study whether the autokinetic phenomenon could be conditioned in human *S*s, and if so, what would be the effects of differences in mental set and degrees of active participation. Factorial design was used so that the 16 *S*s experienced two major experimental conditions. Eight of the *S*s merely reported after each trial whether the light moved, and its direction and distance (Passive group), while the remaining eight *S*s also drew heavy arrows after each trial in the same direction and the same distance that the light was seen to move (Active group). Furthermore, four of the Active and four of the Passive *S*s were instructed that the light would move during *most* of the trials, while the remaining *S*s were instructed that the light would move during *only some* of the trials. These last two sets of *S*s composed the Most and Some groups respectively. All *S*s were rewarded for 'perceiving' movement to the left and punished for 'seeing' movement to the right.

The total experiment was composed of six sessions of 28 trials each. The first five sessions were identical, and were designed to establish conditioning. Ten additional trials followed at the end of Session 5, during which the *S*s rated themselves in terms of their confidence that their perceived movements were correct. The instructions of Session 6 were also altered in order to measure the stability of the conditioned responses established during the first five sessions. Measures were obtained of the frequency that the light was seen to move, the direction of movement (left or right), the degree of conditioning, the magnitude of the movements, the degree of the *S*'s confidence that the perceived movements were correct, the stability of the conditioned responses, and the degree of motor reinforcement in the Active group.

The results of this study justify the following conclusions:

1. The *Ss* who assumed the more active role during the experiment 'saw' the light move more frequently and farther, were more effectively and stably conditioned to see it move in the left (or reinforced direction) and were more confident that their perceptions were correct, than the *Ss* who remained passive during the conditioning sessions.

2. Similarly, the *Ss* who were told that movement would occur during most of the trials 'saw' the light move more frequently and farther, were more effectively and stably conditioned to perceive movement to the left, were more confident that their perceptions were correct, and in the Active group, pressed down harder in making their arrows, than the *Ss* who expected the light to move during only some of the trials.

3. To account for certain findings of the present experiment, it seemed necessary to postulate a Law of Active Participation, to the effect that when an individual assumes an active role in a learning situation, (*a*) he tends to acquire the responses-to-be-learned more rapidly, and (*b*) these response-patterns tend to be more stably formed, than when he remains passive.

(Manuscript received December 6, 1943)

BIBLIOGRAPHY

1. ADAMS, H. F. Autokinetic sensations. *Psychol. Monogr.*, 1912, **14**, No. 59, 1–45.
2. ADRIAN, E. D., & YAMAGIWA, K. The origin of the Berger rhythm. *Brain*, 1935, **58**, 323–351.
3. BAIR, J. H. Development of voluntary control. *Psychol. Rev.*, 1901, **8**, 474–510.
4. BILLS, A. G. The influence of muscular tension on the efficiency of mental work. *Amer. J. Psychol.*, 1927, **38**, 227–251.
5. BOURDON, B. *La Perception visuelle de l'Espace*, 1902, 333–342.
6. CARR, H. A. The autokinetic sensation. *Psychol. Rev.*, 1910, **17**, 42–75.
7. CHARPENTIER, A. Sur une illusion visuelle. *Comptes rendus*, 1886, **102**, 1155–1157.
8. COURTS, F. A. Relations between experimentally induced tension and memorization. *J. exp. Psychol.*, 1939, **25**, 235–256.
9. DERNOVA-YARMOLENKO. (Reported in: Razran, G. H. S. Conditioned responses in children. A behavioral and quantitative critical review of studies. *Arch. Psychol.*, 1935, No. 148.)
10. ELLSON, D. G. Hallucinations produced by sensory conditioning. *J. exp. Psychol.*, 1941, **28**, 1–20.
11. ELLSON, D. G. Experimental extinction of an hallucination produced by sensory conditioning. *J. exp. Psychol.*, 1941, **28**, 350–361.
12. FERREE, C. E. The intermittence of minimal visual sensations. *Amer. J. Psychol.*, 1908, **19**, 58–129.
13. FERREE, C. E. The streaming phenomenon. *Amer. J. Psychol.*, 1908, **19**, 484–503.
14. GATES, A. I. Recitation as a factor in memorizing. *Arch. Psychol.*, 1917, No. 40.
15. GUILFORD, J. P. 'Fluctuation of attention' with weak visual stimuli. *Amer. J. Psychol.*, 1927, **38**, 534–583.
16. GUILFORD, J. P., & DALLENBACH, K. M. A study of the autokinetic sensation. *Amer. J. Psychol.*, 1928, **40**, 83–91.
17. HAGGARD, E. A. Experimental studies in affective processes: I. Some effects of cognitive structure and active participation on certain autonomic reactions during and following experimentally induced stress. *J. exp. Psychol.*, 1943, **33**, 257–284.

18. Haggard, E. A., & Babin, R. The relative effectiveness of motor-reinforcement and reward-reinforcement in conditioning the autokinetic phenomenon. (In preparation)
19. Hudgins, C. V. Conditioning and voluntary control of the pupillary light reflex. *J. gen. Psychol.*, 1933, **8**, 3–51.
20. Humphreys, L. G. The effect of random alternation of reinforcement on the acquisition and extinction of conditioned eyelid reactions. *J. exp. Psychol.*, 1939, **25**, 141–158.
21. Jasper, H., & Shagass, C. Conscious time judgments related to conditioned time intervals and voluntary control of the alpha rhythm. *J. exp. Psychol.*, 1941, **28**, 503–508.
22. Jenkins, J. G. Instructions as a factor in 'incidental' learning. *Amer. J. Psychol.*, 1933, **45**, 471–477.
23. Lashley, K. S. Patterns of cerebral integration indicated by the scotomas of migraine. *Arch. Neurol., Psychiat.*, 1941, **46**, 331–339.
24. Leavitt, H. J. Some differences between unconscious and conscious processes as revealed by unconscious conditioning technique. (*Unpubl. Senior Honors Thesis*) Harvard Univ. Library, 1943.
25. Levine, R., Chein, I., & Murphy, G. The relation of intensity of a need to the amount of perceptual distortion: A preliminary report. *J. Psychol.*, 1942, **13**, 283–293.
26. Menzies, R. Further studies in conditioned vasomotor responses in human subjects. *J. exp. Psychol.*, 1941, **29**, 457–482.
27. Miller, J., & Cole, L. E. The influence of a "voluntary" reaction upon the development and the extinction of the conditioned eyelid reaction. *J. genet. Psychol.*, 1936, **48**, 405–440.
28. Murray, H. A. The effect of fear upon estimates of the maliciousness of other personalities. *J. soc. Psychol.*, 1933, **4**, 310–329.
29. Proshansky, H., & Murphy, G. The effects of reward and punishment on perception. *J. Psychol.*, 1942, **13**, 295–305.
30. Sanford, R. N. The effects of abstinence from food upon imaginal processes: A preliminary experiment. *J. Psychol.*, 1936, **2**, 129–136.
31. Sanford, R. N. The effects of abstinence from food upon imaginal processes: A further experiment. *J. Psychol.*, 1936, **3**, 145–159.
32. Schafer, R., & Murphy, G. The role of autism in a visual figure-ground relationship. *J. exp. Psychol.*, 1943, **32**, 335–343.
33. Schlosberg, H. A study of the conditioned patellar reflex. *J. exp. Psychol.*, 1928, **11**, 468–494.
34. Shagass, C. Conditioning the human occipital alpha rhythm to a voluntary stimulus. A quantitative study. *J. exp. Psychol.*, 1942, **31**, 367–379.
35. Shellow, S. M. Individual differences in incidental memory. *Arch. Psychol.*, 1923, **10**, No. 64.
36. Stroud, J. B. The role of muscular tensions in stylus maze learning. *J. exp. Psychol.*, 1931, **14**, 606–631.

VISUAL SUBLIMINAL PERCEPTION WHERE A FIGURE IS OBSCURED BY THE ILLUMINATION OF THE GROUND

BY H. E. KING, CARNEY LANDIS AND JOSEPH ZUBIN

Psychiatric Institute, Columbia University

Suppose we project on a ground glass screen an illuminated area having the shape of a circle, a square or a triangle and ask an observer to report which form he sees. This he can do easily with complete accuracy. Next, let us turn spotlights on the illuminated area and flood it with so much light that the *S* can no longer 'see' the figure even though it is still being projected. The *S* reports he sees nothing save a brightly illuminated uniform field or ground, and cannot see anything which indicates to him that a circle, square or triangle is being presented. We then ask him to look at the ground and to guess what the figure (form) might be. In similar experiments, using a series of such guesses, others have found that the reports given are more often correct than would be expected by chance. This phenomenon of reporting correctly (better than chance) we shall call *subliminal perception.* Many workers have investigated this phenomenon or other phenomena closely allied to it, but the explanation is still unknown. The present study reports its occurrence and variation under a hitherto uninvestigated set of conditions. A resumé of studies in this field, together with the various possible explanations advanced, has been given recently by Williams (**3**) and by Vinacke (**2**), on whose findings we base the present experiment.

Our study has been designed to provide information relevant to the following questions:

1. How does the accuracy of subliminal perception obtained when the eye is functioning under full daylight conditions compare to its function in dim illumination (Williams) and complete dark adaptation (Vinacke)?

2. How is the accuracy of subliminal perception affected by varying the level of figure and ground illumination with the light-adapted eye?

3. Is the accuracy of report a function of the 'distance' below the previously determined visual discrimination threshold?

Experimental Conditions

The *S* sat in a comfortable chair in a large laboratory room which was well illuminated by three windows providing full daylight conditions. He faced at a distance of five feet a ground

glass screen which was shaded on all four sides by a hood of black felt extending 30 in. toward him. The ground glass was covered with a sheet of black cardboard in which a circle 3½ in. in diameter had been cut. This circle afforded the field or ground on which the forms were projected from the rear, and upon which field two spotlights were focused. Attached to the *S*'s side of the ground glass but behind the cardboard and just below the circular field was the photoelectric receptor of a G-M Laboratories sensitive light-meter. Any illumination reaching the *S*'s field fell equally on this receptor, thus affording a measure of the apparent foot-candles of illumination of the field. Placed on the opposite side of the screen from the *S* a slide projector was set 40 in. from the screen. By means of slides sharp images of a circle, square, or equilateral triangle were projected onto the field. These figures were all approximately two in. high and of such size as to allow the same amount of illumination to fall on the screen. On either side of the direct line of figure projection was a small spotlight 30 in. behind the screen. Illumination was furnished in the projector and in each spotlight by a 200-watt clear Mazda projection lamp.

The voltage reaching the figure projection lamp and the voltage reaching the two spotlight lamps which furnished the ground illumination were controlled by variacs. Manipulation of these two variacs gave smooth, accurate control of the luminosity of both figure and ground, while the absolute luminosity for either, at the screen, could be read directly from the light-meter. A cage, covered with black felt, enclosed all this equipment except the projector and the light-meter. This covering prevented any light from reaching the field except that from the lamps.

The projector lens was extended into the cage by means of a pasteboard funnel which was cut across by a sliding shutter so that the projection of the figure could be interrupted or changed without turning off the lamp.

The *E* sat back of the projector. He could control the luminosity of the figure and of the ground, shift the figure presented and the length of time it was presented, and record the responses of the *S*. He signaled by means of an electric buzzer when the figure was presented and when it was removed, so indicating that a guess should be made by the *S*.

Fifteen *S*s (11 male, 4 female) were used. Four were trained psychologists and 11 were undergraduate students, naïve so far as psychological experiments were concerned. The four psychologists were used as control *S*s for the planning of the experimental conditions of the main experiment. Twelve *S*s were used in the main experiment here reported.

In order to rule out the effect of such factors as position, fatigue, successive levels of luminosity, etc., the order of stimulus presentation was randomized. The forms used, their brightness level and the 'distance' from the threshold were systematically varied so that none might have favor. Measurements of the general room illumination were made before each *S* was tested so that no gross inequalities in daylight illumination could affect the results. All *S*s were light-adapted. All results were obtained during 10 successive days and under conditions very similar with respect to daylight, time of day, weather, etc.

Each *S* was given the following instructions:

> "I am able to project on the field which you view three different figures—a circle, a square and a triangle. By varying the amount of background light they may be made either difficult or easy to see. I am going to start at a point at which you can see the figure easily and then, gradually increase the background light—you are to report when you can no longer see the figure." (The visual discrimination limen was then determined.)
>
> "Now I am going to project these figures at a level at which you cannot see them, but each time I want you to guess the figure you believe is being presented. When you hear a single buzz you are to look at the field. After a short interval you will hear a double buzz which is your signal that the stimulus has ceased and you are to guess which of the three forms you believe it might have been.
>
> "If at *any* time during the experiment you think you *actually do see* either the circle, the square or the triangle you are to report it. The figures are presented in random order and thus may occur in any sequence. You will be given rest periods during the course of the experiment in order to rest your eyes. Look around the room, if you so desire, between presentation of the stimuli."

As the directions indicate, this experiment is based on the differential limen determination procedure: we were working at and below the limen of conscious discrimination between figure and ground where a figure of a given brightness and form is obscured or concealed by a ground of greater brightness superimposed upon it. This procedure served two ends: (*a*) this discrimi-

nation limen can be moved through practically the entire range of brightness discrimination, and (*b*) we can be certain that the stimulus (the figure) is physically present. This latter point is important; since light-meters are less sensitive than the human eye one can by no means be sure whether or not a stimulus is actually being projected if we rely only on mechanical settings below the perceptual limen.

Three levels of figure brightness were explored. The *low* brightness of the figure was set at 0.024 foot-candles. This brightness under the conditions of our experiment was dim, but clearly visible. It was flooded with a ground brightness of *ca.* 17.4 and 28.8 foot-candles respectively, with small deviations from individual to individual. *Medium* brightness figure was 0.102 foot-candles; this was plainly visible. It was flooded with a ground brightness of *ca.* 87.1 and 147.7 foot-candles. *High* brightness figure was 0.324 foot-candles. This was flooded with *ca.* 301.5 and 368.5 foot-candles. This flooding was near the limit of brightness intensity that could be used without too much visual discomfort. Note that the range of ground brightness is great and the intensities high in contrast to figure. Both range and intensity of ground illumination were worked out by experiment with each *S*.

For each figure brightness, the *S* was tested at two levels of ground brightness. The first level was slightly brighter (usually about five foot-candles) than *S*'s experimentally determined discrimination threshold. The second ground brightness was about two steps (j.n.d.'s) brighter as observed or from 10 to 60 foot-candles more than the determined limen (depending on the level of figure brightness). Each *S* gave 180 responses, 60 at each of the three figure levels. The basic group of 12 *S*s provided 2160 responses. On several occasions stimuli were reported as actually seen early in the series. When this occurred the ground level was raised until the figure was no longer visible and a new series was begun. This was actually a further step in limen determination, since these responses were not credited. The 2160 responses upon which we have reported were all unseen and may be regarded as true guesses.

The discrimination limen for each figure brightness level was determined immediately before actual testing at that level in order to take into account any fluctuation of limen with time or adaptation changes due to experience at previous levels of illumination. After each such determination *S*s were given a few sample trials to familiarize them with the guessing task and also to see whether or not the limen as determined remained constant. After satisfactory establishment of the limen an uninterrupted series of 30 responses was taken, with a rest period at the end of the series. Any spontaneous remarks of the *S* during the course of the experiment were noted, but the introspective reports which were obtained from each *S* were not called for until the conclusion of the entire experiment.

Results

Group Data for 12 Ss: In order to obtain an overall picture of the significance of the data for the entire experiment, the total number of correct and incorrect responses was compared with the corresponding number expected by chance. Since there were three choices for each response, the expected number of correct guesses was one-third, or 720. Instead, 922 of the total number of 2160 responses, or 43 percent, were found to be correct, giving rise to a discrepancy which could occur by chance less than one time in 100. Consequently, the hypothesis that these 2160 responses were 'pure guesses' is not tenable, and some subliminal perception factor (or some other undisclosed factor) was responsible for the high proportion of correct responses.

To examine this total result further, the data were analyzed for each level of the three experimental factors under investigation, viz., figure intensity, ground intensity and form of stimulus (circle, triangle and square). The purpose of this analysis was to determine whether each of the levels in the three experimental factors produces results

above chance. This analysis is summarized in Table I, from which it will be noted that variation under all conditions was in the positive direction (above chance) and that a significant critical ratio was obtained in each case.

This statistical procedure demonstrates that subliminal perception does occur under these conditions when we group all our data. Next, we turn to the examination of the *relative* importance of factors which may act to produce the phenomenon. Statistically speaking, do each of the several means for each factor vary from one another by chance, or does some particular level of a factor produce a significant result

TABLE I

COMPARISON OF MEANS FOR EXPERIMENTAL CONDITIONS WITH THEIR CHANCE EXPECTANCY FOR THE TOTAL GROUP

	Observed Mean	Expected Mean	$\sigma_{freq.}$*	Critical Ratio
Figure Intensities				
Low	284	240	12.65	3.48
Medium	304	240	12.65	5.06
High	334	240	12.65	7.43
Ground Intensities				
Low	482	360	15.49	7.88
High	440	360	15.49	5.16
Form				
Circle	287	240	12.65	3.72
Triangle	319	240	12.65	6.25
Square	316	240	12.65	6.01
Total	922	720	21.91	9.22

* The standard error of the expected frequency is obtained from the binomial development $\sigma = \sqrt{pqN}$ where p = probability of success = $\frac{1}{3}$, $q = 1 - p$ and N is the number of presentations for each condition. Thus, for the low figure intensity, the expected mean is $\frac{1}{3}(720) = 240$; and $\sigma = \sqrt{\frac{1}{3} \cdot \frac{2}{3} \cdot (720)} = 12.65$. (Yule, G. U. *An introduction to the theory of statistics.* (8th edition) Griffin, London, 1927, p. 300.)

over and above other levels? An analysis of variance of the group brings out such relations which may be summarized as in Table II.

From the F-ratios we may interpret the importance of the factors producing the total deviation. The influence of figure and ground brightness and of form are not statistically significant. Variation due to differences between individual *S*s and to interaction between all factors are both significant. It should be noted that the variation between individuals is significantly smaller than chance alone would permit; hence, whatever factor is at work to produce accuracy serves also to minimize individual differences. The variation between individuals is significantly less than chance expectancy, probably because they are all following the same general pattern of guessing above

TABLE II

Factor	Sum of Squares	DF	Mean Squares	F
Figure	17.59	2	8.79	±4.18
Ground	8.17	1	8.17	±3.68
Form	8.68	2	4.34	±1.95
Individuals	169.65	11	1.59	−1.4
Interaction	562.34	199	2.83	+1.27
Total	766.43	215		
σ^2 chance			2.22	

The symbol '±' means not significantly different from chance; '−,' significantly smaller than chance; '+,' significantly larger than chance ($P = .01$).

chance. The interaction variance is statistically significant, but the explanation for this is obscure. The effect of such specific combinations will be discussed more definitely with the treatment of the results for individuals.

How often is a symbol called by its proper title, and to what extent do 'mistaking tendencies' exist (e.g., to call a circle a square)? A summary of the χ^2 analysis (Table III) showing the distribution of responses according to the form of the stimulus serves to reinforce the general hypothesis and to make clear possible 'confusion' values.

TABLE III

	Circle*	Triangle*	Square*	Total
Circle**	10.41	7.91⁻	1.67⁻	19.99
Triangle**	2.46⁻	30.87	15.90⁻	49.23
Square**	2.66⁻	6.99⁻	18.21	27.86
Total	15.53	45.77	35.78	98.08

− = a deviation below the level of chance expectancy.
* = stimulus; ** = response.

It is apparent that little confusion exists. The group tended to respond correctly to the three forms significantly more often than would be expected by chance. The large deviations in favor of the correct choice necessarily produce a deficit in the incorrect responses, that is, the significant correct judgments produce consequent significant negative distributions of the incorrect responses. In the case of the square, it is apparent that when it is guessed wrong, the guess is more apt to be a circle than a trianlge. No such preferences exist for the other stimuli.

Individual Results: Table IV gives the comparison for obtained and expected scores for each of the 12 *S*s. Six *S*s gave results that show

a statistically significant deviation from chance; four showed a deviation in excess of chance although not significant; while the guessing of two *S*s was slightly poorer than chance. By chance alone we would expect approximately equal numbers above and below the expected number of 60 correct out of the 180 presentations. The probability of getting only two below expectancy out of 12 is less than three in 1000. Hence we may conclude that the results of the experiment cannot be attributed merely to the influence of the four *S*s whose results were significant in themselves, but that the group as a whole individually and collectively showed a significant deviation above chance.

An analysis of variance was made for the distribution of scores for each individual. Nothing would be gained by including here all

TABLE IV

THE SIGNIFICANT CORRECT RESPONSES BY INDIVIDUALS

Subject	Difference $(o-e)$	Critical Ratio $\frac{D}{\sigma_D}$
1	17	2.68*
2	11	1.74
3	12	1.89
4	9	1.42
5	24	3.79*
6	48	7.59*
7	34	5.37*
8	37	5.85*
9	18	2.85*
10	−5	−0.79
11	−7	−1.11
12	4	0.63

o = The observed number of correct responses; e = expected (60); $\sigma_D = 6.324$.
* indicates those individually significant.

pertinent data obtained during this analysis, but the final results of all of the individual analyses indicate that the systematic variation in the experimental conditions did not affect the performance of the *S*s in a uniform manner. Two of the *S*s showed a significant effect for the factor of figure luminosity. That is, they were significantly more accurate in their responses to one figure luminosity than to the others. Similarly two *S*s showed a significant effect for the factor of form, and one *S* showed a significant effect of the ground luminosity. Two other *S*s showed a significance in the interaction between factors, that is, some combination (or combinations) of two or more of the experimental factors.

To sum this up, when an analysis was made for each individual it was observed that several showed variation of some factor to the point of significance, but that there was no consistent factor (or

division of a factor) for which this held true for even a small number of *S*s. This indicates that there was no constant experimental effect (laboratory artifact or purely an interaction effect of two or more experimental factors) which produced success above chance throughout the sampling of *S*s. Subliminal perception is based on something other than the combinations of experimental factors here varied and analyzed.

Introspective Reports: A careful record of the remarks and reports of the *S* was kept in each case. Several tendencies which held throughout the group are worth mentioning. All *S*s reported that the responses were pure guesswork as they had no cues on which to base their guess. The majority had the feeling that since it was guesswork, they were doing no better than chance; one reported feeling that she had done slightly better than chance; and one believed that he was doing even worse than chance. Reports of attempted systematic variation of response were not as common as was anticipated; eight *S*s reported no such attempt and four said they thought they had noticed a tendency to distribute their guesses. Ghost-figures, fleeting images and some after images were reported as common. An interesting point is the fact that many reported a desire to change their response, that is, having called one form they immediately wished that they had said another. Sometimes this change was made; more often nothing was said. Introspections on the whole revealed that the *S*s had no system or certainty about their task; it seemed altogether a matter of guessing.

Variations of the Procedure: Two innovations were tried with two additional *S*s. One individual was exposed to the same routine as the original 12 *S*s, but instead of the systematically randomized forms he was presented with one form constantly throughout an entire series. That is, he was presented a single form constantly but given the same instructions that had been given to the original group. Sixty trials were given with a constantly presented circle, 60 with a triangle, and 60 with a square. It was thought that by such a procedure we might be able to produce a predominance of response of the form which was being constantly projected for that series. The results for this individual were above chance but not to the point of statistical significance.

Another *S* was put through the exact procedure as the original 12, but was given a blank series; no forms were presented. The obtained results followed chance expectancy.

Pattern Guessing: It was thought that if the *S* was made to guess the figures in groupings of three, the task might be more clearly outlined; that the forced distribution would eliminate unsystematic attempts at variation in guessing; and that, in general, the procedure would lend itself to more exact statistical treatment. Projection

slides were made so that the three forms, in any of their six possible orders of combination, might be presented simultaneously.

A complete series using these combination presentations was run on the same 12 *S*s, but the results were, in general, not significant. All reported the task as being much more difficult, even though it was guesswork. The size of each form was necessarily smaller than those of the forms presented singly; this may have served to discount subliminal perception. Of the 12 *S*s tested, nine made total scores above chance and three made total scores less than chance. Of the nine whose scores fell above the chance level, one was significant at the .01 level and four were significant at the .05 level. Of the three *S*s whose score fell below chance, none had a significant deviation. From this we conclude that a tendency toward accuracy did occur. Since the results on the whole were of less certain statistical significance than those in the main experiment, the data were not analyzed further.

Relation of Threshold to Accuracy of Recognition: For six of the *S*s we determined and recorded in foot-candles the differential threshold at the medium level of the experiment (medium figure brightness and the first level of ground brightness). There was a slight tendency for the *S*s with the lower differential limens (i.e., those for whom the brightness of the figure and the ground were nearer together) to be more accurate in their responses than those with the higher differential limens, but this difference was not statistically significant.

For four *S*s the complete data under the six experimental conditions were analyzed. An analysis of covariance was made for the 24 threshold determinations of these *S*s and their corresponding levels of accuracy. Here again slight inverse relationships were obtained between threshold level and accuracy of guessing, but these differences were not statistically significant.

Action of Red Filter: Subliminal perception, as investigated by Williams (**3**), appeared when the eye was adapted to dim illumination. It was also in evidence when the eye was dark adapted (Vinacke, **4**). We have found it in full daylight. Miles (**1**) has recently shown that red goggles (Corning No. 2403 red filter) produce the effect of dark adaptation when these goggles are worn in full daylight. "A red filter so chosen as to pass only the deep red would provide illumination usable for central cone vision and at the same time would offer only minimal stimulation to the rods and perifoveal vision" (Miles, **1**, p. 110). It seemed worth while to try the effect of this 'artificial' dark adaption in contrast to ordinary daylight with respect to subliminal perception. Dr. Walter Miles generously loaned us a set of goggles for this purpose.

Table V which is in the same form as that appearing in an earlier section of this paper (Table IV) summarizes our preliminary findings with these red goggles on five of the same individuals who were studied under daylight conditions. It is apparent that wearing the red goggles completely changed the experimental results so that the guessing now becomes much more accurate.

The *S*s report that they do not 'see' the form but that they do experience in an irregular fashion visual cues which afford a sufficient basis for guesses which turn out to be accurate. These cues are reported as flashes and irregular areas which serve as symbols. These

TABLE V

Subject	Difference ($o - e$)	Critical Ratio $\frac{D}{\sigma_D}$
	Ordinary Daylight	
1	17	2.68*
2	11	1.74
3	12	1.89
6	48	7.59*
15	−3	−0.47
	Wearing Red Goggles	
1	44	6.96*
2	28	4.43*
3	24	3.79*
6	55	8.70*
15	67	10.59*

o = observed; e = expected; $\sigma_D = 6.324$.
* = individual's results statistically significant above chance.
− = individual's results falling below chance expectancy (not significant).

cues are not the same form or size as the projected figure nor do they appear at the same place on the field that the figure is projected. Individual *S*s (four of whom were trained psychologists) vary among themselves in their description of the cues.

This finding is now the subject of a more intensive investigation which we hope to report at some later date.

Summary

When illuminated areas having the form of a circle, square or triangle are projected upon a ground glass screen and their visibility is obscured by a flood of higher illumination, *S*s have been shown to guess correctly the form being presented significantly more often than would be expected by chance. The present experiment provides information secured under conditions of daylight adaption relevant to this phenomenon.

Both the group and individual results demonstrate the operation of some factor which produces a degree of accuracy definitely above chance expectancy. By chance alone we would expect 33⅓ percent correct responses; the results obtained indicate that the *S*s discriminated the subliminal stimulus with an accuracy of the order of 43 percent.

No one experimental factor (or interaction of factors) was found to be present which might account for the observed success. The degree of accuracy held throughout the visual range investigated. No relation between the intensity of the subliminal stimuli and the accuracy of response was found; forms were identified equally well at levels just below the threshold (5 foot-candles) and at levels several degrees below the threshold (10 to 60 foot-candles). The form of the stimuli themselves did not affect the accuracy of the response, though the triangle was most often correctly identified.

When the three form-stimuli were presented in sets of three and the *S* was asked to identify the entire set in order, the results showed a similar trend in the accuracy of response. Presentation of a constant stimulus failed to produce a clear predominance of that figure in the responses. The distribution of responses during the series in which no stimuli were presented followed chance expectancy. A slight tendency was observed for an inverse relationship between the level of an individual's threshold and the accuracy of response, but this relationship was not significant.

The introspections reveal that the *S*s regarded the experiment as a guessing game. They had no surety of success and believed their responses to be no more accurate than chance alone would allow.

The introduction of a red filter, originally intended to pass only deep red, allowing central cone vision but offering only minimal stimulation to the rods and perifoveal vision, completely changed the nature of the results, raising the accuracy of response to the order of 50 percent as compared to 33 percent expected by chance. Cues of a symbolic sort which aid the *S*, and which did not appear under daylight vision, were identified.

(Manuscript received October 5, 1943)

References

1. Miles, W. R. Red goggles for producing dark adaptation. *Fed. Proc.*, 1942, **2**, 109–115.
2. Vinacke, W. E. The discrimination of color and form at levels of illumination below conscious awareness. *Arch. Psychol.*, 1942, **38**, No. 267.
3. Williams, A. C. Perception of subliminal visual stimuli. *J. Psychol.*, 1938, **6**, 187–199.

THE EFFECT OF CONTROLLED TEMPERATURE CHANGES ON THE BEHAVIOR OF THE WHITE RAT *

BY KENNETH MOORE

University of Kansas

Recent studies have indicated that the physical and behavioral characteristics of many organisms change as the temperature under which they live is varied. Wheeler (**10**, **11**, **12**), Petersen (**7**, **8**), and Mills (**5**, **6**) have outlined the extent and direction of some of these changes. Other aspects of the influence of temperature on lower animals have been reported by French (**1**), Hunter (**4**), Wever (**9**), and Hack (**2**). Hellmer (**3**) has reported that rats living under controlled temperatures exhibit differences in the rate of development and in efficiency in maze learning. He raised three colonies of white rats under temperatures of 55°, 75°, and 90° F. respectively. In his study, carried through two generations, Hellmer found that rats living at 55° F. grew more rapidly, developed a rounder, heavier body form, and were from two to three times more efficient in learning a simple maze than similar groups living in the room at 90° F.

The present experimental study was an attempt to carry one step further the analysis of the differences Hellmer reported. The main purpose was to find whether the superiority of the rats living at 55° F. held up when the temperature of their environment was increased, and whether the inferiority of the rats living at 90° F. continued when the temperature of their environment was lowered. A secondary purpose was to find how rapidly and completely adaptation to the new conditions would take place. Preliminary measures of some of the motivational factors involved were also made, and will be reported in a subsequent paper.

Procedure

In general, the same experimental conditions were maintained as were used by Hellmer. Parts of his work were repeated, but new colonies of animals were employed.

Different temperatures were maintained in three small, well insulated rooms. A Frigidaire unit maintained a temperature of 55° to 58° F. in the cold room. The temperature of the second room, which served as a control for the present study, varied with the temperature of the building (75° to 79° F. during the experimental period). An electric heater and thermostat in the third room kept a constant temperature of 88° to 90° F. Electric fans in all rooms provided circulation of the air. A shallow pan of water in front of the fan in the hot room aided in keeping the relative

* This paper is a condensation of a thesis presented to the Graduate School of the University of Kansas in partial fulfillment of the requirements for the Ph.D. degree. The author is indebted to Dr. R. H. Wheeler, under whose direction this study was carried out.

XUM

humidity roughly equal to that of the cold room. The relative humidity range in the hot and cold rooms was from 50 percent to 75 percent. In the control room the relative humidity varied with changes in the entire building.

The experimental rats were taken from 35 healthy albino litters. When four weeks old, the rats were weaned and placed in the experimental rooms. The litters were divided so that some members from each litter were placed in each of the three rooms, as nearly as possible in equal numbers. The groups were also equated with regard to sex and average weight. The rats were numbered at the time of division, and weekly weight records were maintained until the end of the experiment.

The same diet was provided for all rats by keeping Purina Fox Chow pellets in the cages at all times. Fresh lettuce was added once a week. Excelsior was placed in the cold room cages for extra bedding. With this exception, however, all other environmental conditions in the three rooms were kept as nearly comparable as possible.

Maze behavior was the most important variable investigated. Standard four-alley mazes, similar to those used by Hellmer, were placed in the experimental rooms during maze trials. The starting box and food box doors were controlled from outside the room by means of strings. A small window in the door of each room enabled *E* to record from the outside the errors and time per trial of the rat in the maze. Illumination of the mazes in each room was kept uniform by placing a 40-watt light two feet above the center of each maze.

In order to measure the performance of the same rat in two situations, original and changed temperatures, two tests were given each animal. The first test was conducted in the room in which the rat was originally placed. After learning the maze, the rat was then moved to a room of different temperature, and 40 days later was tested for retention (relearning). For example, 45 rats placed in the cold room at four weeks of age were required to learn the maze in that room. After learning, the group was divided into three subgroups of 15. Division was made to equate sex and mean trials required for mastery of the maze. Two subgroups of 15 were then placed in one of the other two temperature conditions. Thus, one subgroup was left in the cold room, a second was placed in the control room, and a third was moved to the hot room. Approximately 40 days after learning the maze, the rats were tested for retention.

The same procedure was carried out with the rats originally placed in the control and hot rooms. In cases where the subgroups were moved from one extreme temperature to the other, a seven-day adjustment period in the control room was introduced. This was done in order to avoid a sudden change in temperature that might be too severe for the animal.

Learning began when the rats were from 85 to 95 days of age. All rats were deprived of food for 24 hours before the first trial. Gains Dog Meal mixed with enough milk to form a paste was used as the incentive. Each rat was given one trial the first day of maze running, three trials per day for the next three days, and five trials a day thereafter. After a total of 37 trials, each rat was given 10 trials per day until 80 trials had been made. Twenty min. was set as the time limit per trial. After an incomplete run the rat was allowed to eat in the food box for 30 sec. before the next trial was started. If a rat refused to run after seven successive incomplete trials, it was removed from the experiment. On completion of each trial the rat was allowed to eat in the food box for approximately 20 sec. before starting on the next run. At the end of each day's trials, the rats were fed for 20 min. on the same food as was used in the maze. No more food was given until completion of the trials the next day. The criterion of learning was set at three consecutive errorless runs. Entrances into a blind alley beyond the shoulders, or back-tracing any unit of the maze, were considered as errors.

Retention tests were begun approximately 40 days after original learning. Three trials were given the first day, five trials the second day, and 10 trials a day thereafter until the maze was relearned. The criterion of learning was again three consecutive errorless runs. A 20-min. time limit per trial was also used, and the rat removed from the experiment after five successive incomplete runs. Other experimental conditions were the same as in the original learning.

Results and Discussion

Weight Records.—The general picture obtained from the weekly weight records corresponded to that reported by Hellmer. The rats living in the cold room grew rapidly and exhibited the greatest average

weight each week. The average weight of the hot-room rats was the smallest for the three groups. At the time when the litters were divided and placed in the rooms, the average weights for the cold, control, and hot rooms were 45.9, 44.1, and 44.7 gm., respectively. At the end of the tenth week these values were 157.9, 145.7, and 141.5 gm., respectively. For those rats remaining in the original rooms throughout the experimental period, the average weights at the end of the eighteenth week were 234.0 gm., 206.9 gm., and 198.8 gm. for the cold-, control-, and hot-room groups.

It will be remembered that some of the rats from each room were placed in rooms of different temperature after original learning. This shift took place when the rats were from 12 to 13 weeks old. The changed temperatures might well be expected to influence the rate of growth of the rats moved to new conditions. A study of the growth curves for the nine groups of rats (not reproduced here) indicated that switching a group from one extreme temperature to the other (hot to cold or cold to hot) acted to reduce the rate of growth below that of groups left in the original room or placed in the control room. For example, the cold-room group, after placement in the hot room, showed a slower rate of growth than did equal groups placed in the control room or left in the cold room. A trend in this direction would have been expected on the basis of the rate of growth in the three rooms during the fourth to tenth weeks of the experiment. However, it was found that placing a group from the hot room in the cold room did not accelerate its development beyond that of similar groups left in the hot room. On the contrary, the hot-room group placed in the cold room showed the slowest rate of growth of the three subgroups originally from the hot room. Moving rats started in the control room either to the hot or cold room served to stimulate the rate of growth. The increases were slight, however, and may not have been significant.

Body Measurements.—Hellmer also reported certain morphological changes in rats living under different temperatures. In order to check his results, tail lengths and body lengths were measured in those rats remaining in the original rooms throughout the course of the experiment. All the measurements obtained confirmed Hellmer's observations. Table I presents these values in detail. The measurements were made on an equal number of males and females in each room.

The tail lengths were found to increase as the temperature of the surroundings was raised. The values for $\sigma/\sqrt{N}$ also indicate that these means are reliable. As measured by the critical ratios, the differences between the tail lengths were statistically significant. The critical ratio for the C-X [1] group was 4.1, for the C-H group,

[1] The symbols C, X, H refer to the groups originally placed in the cold, control, and hot rooms, respectively.

6.8, and for the X-H group, 3.0. Smaller differences in body length were noted, and these differences were not statistically significant.

It was found, however, that a ratio of body length to tail length gave a better picture of the relative body and tail lengths in each room. The values for this ratio indicated that the cold-room rats not only had shorter tails in terms of absolute measurements, but also relatively shorter tails when compared to body length. The ratio of body length to tail length for the cold-room group was 1.21. The value declined to 1.13 for the control-room group and to 1.07 for the hot-room rats.

A second ratio, body weight to body length, gave a picture of the differences in body type which developed in the three rooms. This ratio gave the gm. of body weight per cm. of body length. The maximum value of 11.7 gm. per cm. of body length was found for the cold-

TABLE I

MEAN TAIL AND BODY LENGTHS FOR RATS SPENDING ENTIRE PERIOD IN SAME ROOM

Room	No.	Tail Length (cm.)			Body Length (cm.)		
		Mean	σ	$\sigma/\sqrt{N}$	Mean	σ	$\sigma/\sqrt{N}$
Cold	30	16.5	.90	.16	20.0	1.4	.22
Control	38	17.4	.99	.16	19.7	1.4	.22
Hot	36	18.0	.86	.14	19.3	1.2	.19

room group. Values for the control- and hot-rooms were 10.5 and 10.3, respectively.

Thus, repetition of a portion of Hellmer's study gave further demonstration of the changes in body structure in the process of adaptation to different temperatures. As Mills (**5**) has suggested, exposure of a greater surface area, especially tail area in the case of the rat, no doubt facilitates loss of body heat. In the rooms of higher temperature, greater amounts of body heat must be lost to maintain proper physiological functioning.

Maze Performance.—Standards for maze performance in each room were first established. Equal groups, in terms of trials required for mastery of the maze, were then placed in each of the three temperatures and the relearning scores were determined forty days later. Table II gives the mean trials, errors, and time, the three criteria used, required for mastery of the maze the first time.

It will be noticed that those rats placed in the cold room and learning the maze there were superior to the other two groups in all three criteria. The control-room rats were second in all three measures, while rats living and learning in the hot room showed the poorest

TABLE II

MEAN TRIALS, ERRORS, AND TIME REQUIRED FOR ORIGINAL LEARNING

Group	No.	Trials			Errors			Time (sec.)		
		Mean	σ	$\sigma/\sqrt{N}$	Mean	σ	$\sigma/\sqrt{N}$	Mean	σ	$\sigma/\sqrt{N}$
Cold	47	19.8	7.36	1.07	141	72.3	10.5	4443	2926.5	426.6
Control	46	25.9	13.30	1.96	143	80.7	11.9	5180	3664.8	540.5
Hot	47	36.6	19.10	2.78	245	131.8	19.2	8270	5487.9	799.9

performance. As the temperature of the room in which original learning took place increased, the level of performance decreased. Variability of performance changed in the reverse manner; as the temperature increased, variability increased. Values for $\sigma/\sqrt{N}$ also indicated that these averages were reliable.

As measured by critical ratios, the differences between the means of the three rooms were also significant. With trials as the criterion, the critical ratio for the C-X groups was 2.74; for the C-H groups 5.6; and for the X-H groups 3.1. Comparison of errors gave the following values; C-X, .13; C-H, 4.75; and X-H, 4.5. Using time as the standard, the critical ratios were: C-X, 1.07; C-H, 4.22; and X-H, 3.2.

Mean trials, errors, and time in relearning for the nine subgroups are given in Table III. Taking the cold room as an example, it will be noticed that the subgroup of 14 rats which were left in that room and tested for retention approximately 40 days later, took an average of 7.1 trials, 17.4 errors, and 559 sec. for mastery of the maze the second time. A second subgroup from the same room, which learned

TABLE III

TRIALS, ERRORS, AND TIME FOR THE NINE EXPERIMENTAL GROUPS—RELEARNING

	N	Trials			Errors			Time (sec.)		
		Mean	σ	$\sigma/\sqrt{N}$	Mean	σ	$\sigma/\sqrt{N}$	Mean	σ	$\sigma/\sqrt{N}$
Cold-Room Rats										
a. Left in C	14	7.1	4.15	1.1	17.4	18.37	4.90	559	732.0	195.7
b. Moved to X	17	9.8	4.77	1.1	31.8	25.11	6.09	1090	1052.1	255.4
c. Moved to H	14	13.0	6.48	1.7	50.6	31.80	8.50	1336	1187.3	317.5
Control-Room Rats										
a. Moved to C	14	7.9	3.45	.9	31.3	32.08	8.58	702	715.4	191.3
b. Left in X	15	11.3	6.77	1.8	40.0	38.56	9.96	2009	2778.1	717.9
c. Moved to H	15	18.8	9.22	2.4	70.4	46.90	12.10	1909	1576.6	407.4
Hot-Room Rats										
a. Moved to C	16	8.2	3.28	.8	28.9	22.72	6.93	1019	1507.1	376.8
b. Moved to X	15	10.5	4.56	1.2	36.5	43.09	11.10	749	689.8	180.6
c. Left in H	14	16.5	9.76	2.6	47.6	20.32	5.43	1715	2203.9	589.3

the maze in the cold room in an equal number of trials, but relearned the maze after 40 days in the control room, needed 9.8 trials, 31.8 errors, and 1090 sec. to reach the same standards of performance. A third subgroup, again with an equal score on original learning in the cold room, but moved to the hot room for relearning, required an average of 13.0 trials, 50.6 errors, and 1336 sec. to relearn the maze 40 days later.

The same trend was observed in the original control- and hot-room rats that relearned the maze in each of the three temperature conditions. Every time a subgroup was moved to a room of lower temperature, the number of trials needed decreased, while it increased as equal groups were placed in rooms of higher temperature. With but two exceptions, the same trend was found when total errors were taken as the standard of learning. In both of the exceptions, however, it was the control group that was 'out of place.'

Variability of performance followed a trend similar to that found in original learning. The sigmas increased as subgroups originally from the same room relearned the maze in rooms of higher temperature. This trend was observed in all three of the criteria employed. The differences between the means of groups originally from the same room but relearning in the cold and hot rooms are, for the most part, significant. Critical ratios of the differences in mean trials, errors, and time for rats originally from the cold room but relearning in the cold and hot rooms were 2.9, 3.4, and 2.08, respectively. Similar values for rats from the control room relearning in the cold and hot rooms were 4.27, 2.64, and 2.69, for trials, errors, and time. For the hot-room rats relearning in the cold and hot rooms, the critical ratios were 3.0, 2.13, and .99, respectively.

Vincent curves were constructed to compare the general progress in elimination of errors during maze trials by the different groups of rats. Fig. 1 presents the curves for original learning in the three rooms.

It will be noticed that there was little difference in errors between rats learning in the cold and control rooms. Although the control-room animals started with a greater number of average errors than the cold-room rats, the former eliminated errors rapidly until the later portions of the learning. The cold-room group tended to eliminate errors somewhat more slowly but more consistently. The curve for the hot-room rats had the same general form as the other two groups, with the exception that the former started with greater average errors, and tended to level out during the last portion of the learning. Qualitative observations of maze behavior paralleled the general picture given by the Vincent curves. Rats in the cold room showed steady, consistent progress in the maze. Errors were eliminated methodically,

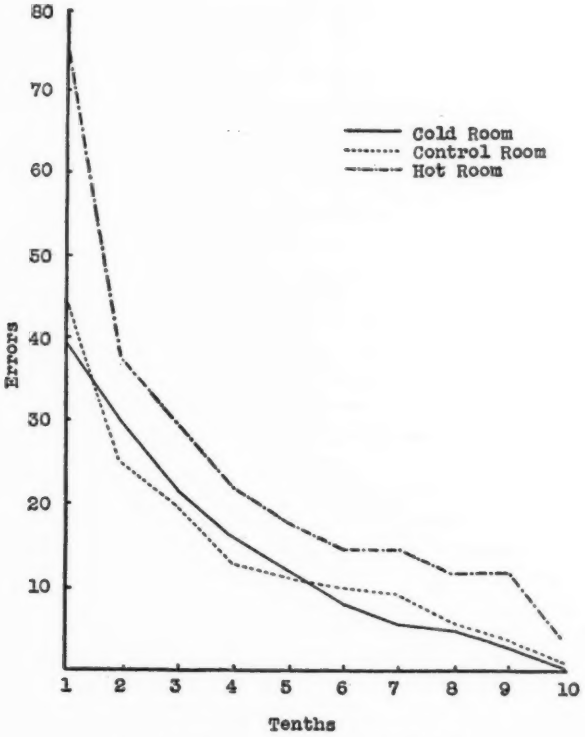

FIG. 1. Vincent curves for original learning

and there were few instances of decreases in level of performance. In the hot room, however, there were many periods of little or no progress in the maze. It was difficult to predict the behavior of individual rats, as there were many trials in which errors tended to increase rather than decrease. This type of behavior was usually found after the rats had been given a number of trials.

Vincent curves for relearning are shown in Fig. 2. In these curves the scores of all subgroups in each room have been combined, so that each curve represents the performance of a room as a whole. The range of errors was large at first, but it diminished rapidly until the mid-point of the learning. At this place, the groups in all three rooms showed about the same level of performance. During the last stages of the learning, however, the rats in the hot room tended to show an increase in average errors. Rats in the cold room continued their steady progress in mastering the maze. The control-room group also eliminated errors at a steady rate, but somewhat more slowly than the

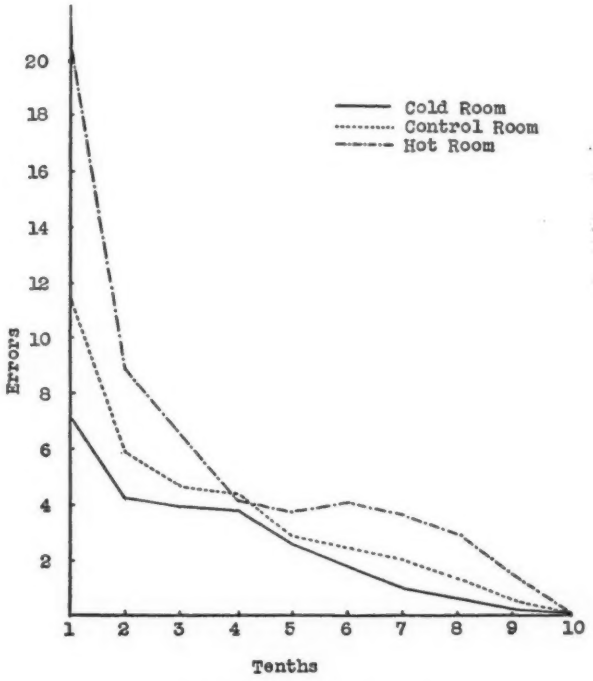

FIG. 2. Vincent curves for relearning

cold-room group. Qualitative observations of the maze behavior of the rats agreed with those made during original learning.

Whether differences found in original learning persisted when rats were placed in new conditions was next considered. If such differences did carry over and influence relearning scores, the subgroups coming from the cold room would be expected to show the best performance of the subgroups in any room, with rats originally from the control and hot rooms standing second and third, respectively. Examination of the relearning scores in the cold room (see Table II) indicated that in terms of trials, the group originally learning the maze in the cold room ranked first, the group from the control room second, while rats originally from the hot room were third. For errors, the rankings were cold, hot, control, and for total time, cold, control, hot. The subgroups relearning in the control room stood in the order cold, hot, control for trials, cold, hot, control for errors, and hot, cold, control for time. In the hot room, the ranking for relearning was cold, hot, control for trials, hot, cold, control for errors, and control, cold, hot for time. Critical ratios for the reliability of the differences be-

tween means were calculated and are presented in Table IV. In general, the values of the ratios are small and do not suggest that there were significant differences in performance of different subgroups in any one room.

TABLE IV

CRITICAL RATIOS OF THE DIFFERENCES BETWEEN MEANS OF TRIALS, ERRORS, AND TIME FOR RELEARNING WITH RATS GROUPED BY ROOMS

	Trials	Errors	Time
In Cold Room			
C–X groups	.57	1.40	.52
C–H groups	.80	1.36	1.08
X–H groups	.24	.22	.75
In Control Room			
C–X groups	.73	.70	1.28
C–H groups	.56	.37	1.11
X–H groups	.38	.23	1.70
In Hot Room			
C–X groups	1.98	1.34	1.11
C–H groups	1.13	.30	.57
X–H groups	.65	1.72	.27

SUMMARY

In order to determine the influence of temperature changes upon the behavior of the white rat, three equal groups were kept under controlled temperatures of 55°, 75°, and 90° F., respectively. At 85–95 days of age, 45 rats in each room were tested for learning in a four-alley maze. Records of trials, errors, and time were kept. After learning, equal groups of 15 from each original room were distributed to the three temperature conditions. Approximately 40 days after learning, each rat was tested for retention. Weekly weight records were kept, and Vincent curves for both learning and retention were constructed. The following results were obtained:

(1) Rats in the cold room grew more rapidly than those in the control or hot rooms. Movement from one extreme temperature to the other tended to retard the rate of development compared with that of rats left in the original room.

(2) The rats remaining in the hot room throughout the course of the experiment developed longer, more slender bodies and relatively longer tails (mean tail length, 18.0 cm.). Similar groups in the cold room were short and stocky, with shorter tails (mean tail length, 16.5 cm.).

(3) Rats living, and learning the maze, in the cold room were superior to similar groups living in the hot room. The control-room group was about midway between the hot- and cold-room groups in

XUM

performance. (Mean trials required for learning in the cold room were 19.8; in the control room, 25.9; and in the hot room, 36.6.)

(4) In relearning, when a group was moved to a room of higher temperature the number of trials required for mastery of the maze increased. Comparisons were made with equal groups left in the original room or placed in the control room. (Rats from the cold room relearned the maze there in 7.1 trials, in 9.8 in the control room and 13.0 in the hot room. Control-room rats needed 11.3 trials in the control room, 7.9 in the cold, and 18.8 in the hot room. The hot-room rats relearned the maze in the hot room in 16.5 trials, in the control room in 10.5, and in the cold room in 8.2 trials.)

(5) Groups of rats originating in different rooms but relearning the maze in the same room, whether cold or hot, showed little significant differences in relearning when all three criteria were considered.

(6) Vincent curves indicated a decrease in performance during the latter portions of the tests in the hot room, especially when relearning scores were examined.

Additional evidence has been presented which confirms Hellmer's conclusion that the temperatures under which white rats live are important conditions of the efficiency of maze learning. The results of the present study indicate that the maze learning ability of the same group of rats varied as the temperature of their environment was changed. It is also concluded that the changes found in performance which corresponded with changes in temperature indicate that adaptation to the new temperatures was fairly rapid and complete under the present experimental conditions.

(Manuscript received December 3, 1943)

References

1. French, J. W. The effect of temperature on the retention of a maze habit in fish. *J. exp. Psychol.*, 1942, 31, 79–87.
2. Hack, E. R. Learning as a function of water temperature. *J. exp. Psychol.*, 1933, 16, 442–445.
3. Hellmer, L. A. The effect of temperature on the behavior of the white rat. *Amer. J. Psychol.*, 1943, 56, 408–421.
4. Hunter, W. S. The effect of inactivity produced by cold upon learning and retention in the cockroaches. *J. genet. Psychol.*, 1932, 41, 253–266.
5. Mills, C. A. *Medical climatology.* Baltimore: C. C. Thomas, 1939.
6. Mills, C. A. *Climate makes the man.* New York: Harper, 1942.
7. Petersen, W. F. *The patient and the weather.* 3 vols. Ann Arbor: Edwards Bros., 1938.
8. Petersen, W. F. *Lincoln and Douglas: weather as destiny.* Springfield, Ohio: Thomas, 1943.
9. Wever, E. G. Water temperature as an incentive to swimming activity in the rat. *J. comp. Psychol.*, 1932, 14, 219–224.
10. Wheeler, R. H. Social behavior patterns and climate. *Soc. Frontier*, 1939, 5, 231–237.
11. Wheeler, R. H. The problem of world climate. *Bull. Amer. Meteorol. Soc.*, 1940, 21, 46–58.
12. Wheeler, R. H. The effect of climate on human behavior in history. *Trans. Kans. Acad. Sci.*, 1943, 46, 33–51.

EYE MOVEMENTS IN READING OPTIMAL AND NON-OPTIMAL TYPOGRAPHY *

BY DONALD G. PATERSON AND MILES A. TINKER

University of Minnesota

In a series of studies (1) we discovered that variation in type size, line width, leading and color of print and background affected speed of reading but that paper surface did not. By introducing simultaneously undesirable variations of these factors we obtained a non-optimal typographical arrangement which retarded speed of reading 22.2 percent in comparison with an optimal arrangement. Although the introduction of each undesirable variation resulted in further decrease in speed of reading, the effect was not cumulative or strictly additive.

In this study a comparison is made between the eye-movement patterns employed in reading text in optimal and in non-optimal typography. The optimal arrangement consisted of type set in ten-point with two-point leading, 19 pica line width, black print on white eggshell paper stock; the non-optimal, of text set in six-point set solid, 34 pica line width, white print (with black background) on white enamel paper stock. All material was printed in Scotch Roman, lower case. The eye-movements were photographed with the Minnesota eye-movement camera.

Each of 20 college students read 10 paragraphs from the Chapman-Cook Speed of Reading Test, Form A set in the optimal arrangement and 10 different paragraphs from Form B of the same test set in the non-optimal arrangement. The photographic records yielded the following analytical measures: number of fixations, number of words per fixation, duration of pauses, perception time and number of regressions.

Examination of Table I reveals striking differences in eye-movement patterns employed in reading the two printing arrangements. In reading the non-optimal text, there were on the average 19.8 percent more fixations, 16.98 percent fewer words read per fixation, 6.24 percent longer pause duration, 27.29 percent longer perception time (sum of pause durations), and 93.3 percent more regressions. All of the differences were significant beyond the one percent level except pause duration which was significant at the five percent level.

* The writers are grateful to the University of Minnesota Graduate School for research grant to finance this study.

XUM

Previous findings will help to explain the trends in oculomotor patterns found in reading the non-optimal typography. In comparing black and white print, Taylor (**6**) discovered that reading white print on black background required significantly more fixations than for reading black print. This resulted in a smaller perceptual span (words per fixation). Pause duration was not affected. (Possible changes in regression frequency were not computed.) When the line width is increased markedly, Paterson and Tinker (**2**) found that all eye-movement measures became less efficient, particularly fixation frequency and regression frequency. There was particular difficulty in accuracy of the back sweep to the beginning of successive new lines of print. In another study (**3**) involving six-point type, the most

TABLE I

MEAN EYE-MOVEMENT MEASURES FOR 20 COLLEGE STUDENTS READING TEXT IN OPTIMAL AND NON-OPTIMAL TYPOGRAPHY

Note: The optimal arrangement consisted of text set in ten-point with two-point leading, 19 pica line width, black print on white eggshell paper stock; the non-optimal arrangement of text set in six-point set solid, 34 pica line width, white print on white enamel paper stock. Pause duration and perception time are reported in seconds. Ten paragraphs from the Chapman-Cook Speed of Reading Test, Form A, were set in the optimal arrangement and 10 paragraphs from Form B of the same test were set in the non-optimal arrangement. All paragraphs were printed in Scotch Roman, lower case.

Typographical Arrangement	Fixation Frequency	Words Per Fixation	Pause Duration	Perception Time	Regression Frequency
Optimal	191.7	1.60	0.22	42.92	21.7
Non-Optimal	229.6	1.33	0.24	54.62	41.9
Differences	+37.9	−0.27	+0.02	+11.70	+20.2
Percent Differences*	+19.8	−16.98	+6.24	+27.29	+93.3

* All differences are statistically significant: pause duration at the five percent level, and the remainder beyond the one percent level.

significant changes occurring when line width was increased from 13 to 36 picas were for regression frequency and pause duration. Another investigation (**4**) revealed an increase in fixation frequency and pause duration when size of type was reduced from ten- to six-point. But with optimal line widths and leading, Paterson and Tinker (**5**) discovered that pause duration was significantly increased when the type size was decreased from eleven- to six-point. Apparently here the poor visibility of the small print was the main factor operating to modify the oculomotor patterns. In all these studies, due to increased fixation frequency or longer pause duration, or both, the perception time was significantly longer. In all instances where the fixation frequency increased, the words per fixation became less.

In summing up the results of the eye-movement studies with certain specific variations in typography, therefore, we find the following

significant trends in oculomotor patterns: (1) changing from black to white print requires more fixations; (2) a marked increase in line width produces the greatest changes (*a*) in fixation and regression frequency with ten-point type, and (*b*) in regression frequency and pause duration with six-point type; (3) reduction in type size (*a*) from ten- to six-point increased fixation frequency and pause duration and (*b*) from eleven- to six-point increased pause duration; (4) in all cases perception time increased.

In this study, where several undesirable typographical factors are introduced simultaneously, their combined effects upon oculomotor patterns are evident. Although the effects are not strictly additive, examination of Table I reveals that the percent difference for each eye-movement measure is greater than for the corresponding measure in previous studies where variation of a single typographical factor was involved, with the exception of pause duration, where the percent difference is approximately the same as found for reduction of type size from ten- to six-point. It is apparent, therefore, that the various non-optimal typographical factors are operating together to produce the oculomoter patterns in this study. Since the effects are not strictly additive, however, their combined effect cannot be predicted exactly from a knowledge of their separate effects.

Summary

1. In a series of reading performance experiments, the writers have demonstrated that a combination of non-optimal typographical factors (white print, long lines, small type, set solid) decreased rate of reading 22.2 percent in comparison with an optimal arrangement of ten-point type, 19 pica line width, two-point leading, printed black on white.

2. Eye movement photographs of a new group of 20 *S*s indicate the precise changes in oculomotor patterns involved in reading the non-optimal arrangement in comparison with the optimal.

3. All discovered differences are highly significant and, with the exception of pause duration, are larger than found when any single undesirable variable is concerned. This suggests that, when several undesirable typographical factors are combined, they operate together to produce inefficient oculomotor patterns although the effects are not additive.

(Manuscript received December 6, 1943)

References

1. Paterson, D. G., & Tinker, M. A. *How to make type readable.* New York: Harpers, 1940. Pp. xix + 209. (Obtainable from the authors)

2. Paterson, D. G., & Tinker, M. A. Influence of line width on eye-movements. *J. exper. Psychol.*, 1940, **27**, 572–577.
3. Paterson, D. G., & Tinker, M. A. Influence of line width on eye movements for six-point type. *J. educ. Psychol.*, 1942, **33**, 552–555.
4. Paterson, D. G., & Tinker, M. A. Influence of size of type on eye movements. *J. appl. Psychol.*, 1942, **26**, 227–230.
5. Paterson, D. G., & Tinker, M. A. Eye movements in reading type sizes in optimal line widths. (In press)
6. Taylor, C. D. The relative legibility of black and white print. *J. educ. Psychol.*, 1934, **25**, 561–578.

CONSISTENT CONDITIONED HAND-WITHDRAWAL IN THE ELEMENTARY LABORATORY

BY HAROLD SCHLOSBERG

Brown University

When one plans an experiment in conditioning for the elementary laboratory course, the first thing he thinks of is the conditioned hand withdrawal. But he is often disappointed with the results, for this conditioned response develops in a very uncertain and irregular fashion. He can make a virtue of this irregularity by referring the students to the extensive literature on attitudinal factors in human conditioning (**1**, pp. 260–273; **3**). But actually it is possible to obtain fairly successful results with this experiment, if one uses a strong shock and spaces the reinforcements adequately.

During the last few years we have consistently obtained conditioned hand withdrawals in over 90 percent of our subjects in 1–1½ hours. We use the arrangement described a decade ago (**5**), modified by the inclusion of a Cenco [1] Impulse Counter. The counter permits regular reading of the latency of response, and also makes a loud buzz, which serves as the conditioned stimulus. A Harvard Inductorium (without automatic interrupter) is connected through two telegraph keys (in series) to a toy transformer. The impulse counter is connected in parallel with the primary of the inductorium. One lead of the secondary goes to a large 'indifferent' electrode on the right wrist of the subject, and the other lead goes to the subject's key, from which the insulating knob has been removed. On the 'Ready' signal, *S* depresses his key. When *E* closes his, the primary circuit is completed, actuating both inductorium and impulse counter. *S* receives a shock from the key, and removes his finger. This opens the circuit, and stops the impulse counter. *E* can then read the latency of the response from the impulse counter. 'Tests' for the conditioned response are made by shorting the secondary of the inductorium about once in 10 stimulations.

One of the chief advantages of timing the latency of each response is that it permits a rough measure of the intensity of the shock. We have adopted the rough rule that the shock must be strong enough to give reflex latencies of 100 ms. or less (12/120 sec.). Longer latencies

[1] Cenco Counters are difficult to obtain at present. Stoelting's Counter is not noisy enough to serve as a conditioned stimulus.

suggest that *S* is not responding reflexly to the shock, but is responding at a 'voluntary' level. Regardless of whether or not our reasoning is correct, the stronger shock seems to get results, in spite of the unfavorable zero time interval between buzz and shock (1, 6).

A second factor that seems to contribute to the success of this experiment is the spacing of paired stimulation. With simple apparatus of this sort, *E* usually attempts to speed up the process by stimulating about every five seconds. There is abundant evidence (1, 2, 4) that this does not have the expected result. We insist that no more than three to four trials be given per minute. A still slower rate might be desirable. Incidentally, we enforce the same rate (four per minute) in an experiment on the conditioned knee jerk, and obtain fairly consistent conditioning. An adequate study of the effects of the intertrial interval in human conditioning is long over-due.

There are two difficulties we encounter with the apparatus described above. *S* sometimes gets a slight shock when the inductorium is not operating. This can be corrected by reversing the wires on his key, or better, by using a separate active electrode, mounted on the insulating knob of the key. The Cenco Impulse Counter sometimes fails to work, especially when the impedance of the inductorium is changed by closing the short-circuiting key. This means that the transformer output is too low, either in voltage or wattage. We use a transformer rated at 100 watts, and vary the voltage between 12 and 24, depending on the condition of the counter. If the voltage is 2–4 v. above the lowest value that starts the counter consistently, the readings are accurate enough for our purposes.

(Manuscript received December 4, 1943)

References

1. Hilgard, E. R., & Marquis, D. G. *Conditioning and learning.* New York: Appleton-Century, 1940.
2. Hovland, C. I. "Inhibition of reinforcement" and phenomena of experimental extinction. *Proc. nat. Acad. Sci., Wash.*, 1936, **22**, 430–433.
3. Razran, G. H. S. Attitudinal control of human conditioning. *J. Psychol.*, 1936, **2**, 327–337.
4. Schlosberg, H. Conditioned responses in the white rat. *J. genet. Psychol.*, 1934, **45**, 303–335.
5. Schlosberg, H., & Carmichael, L. Three new pieces of apparatus from the Psychological Laboratory of Brown University. *Amer. J. Psychol.*, 1931, **43**, 119–121.
6. Wolfle, H. M. Conditioning as a function of the interval between the conditioned and the original stimulus. *J. gen. Psychol.*, 1932, **7**, 80–103.